INVESTIGATION INTO ROLE OF INTRINSIC FACTORS IN THE SPONTANEOUS HEATING OF COALS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF

THE REQUIREMENTS FORTHE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

BY

SANTOSH KUMAR MIRDHA

Roll No. 108MN018

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA - 769008
2011-2012

INVESTIGATION INTO ROLE OF INTRINSIC FACTORS IN THE SPONTANEOUS HEATING OF COALS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF

THE REQUIREMENTS FORTHE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

BY

SANTOSH KUMAR MIRDHA

ROLL NO. 108MN018

UNDER THE SUPERVISON OF

DR. H. B. SAHU

ASSOCIATE PROFESSOR

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA - 769008
2011-2012

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled "**Investigation into Role of Intrinsic Factors in the Spontaneous Heating of Coals**" being submitted by **Sri Santosh Kumar Mirdha** (Roll No. 108MN018) to National Institute of Technology, Rourkela; for the award of degree of Bachelor of Technology in Mining Engineering is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter substantiated in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

Dr. H. B. Sahu
Associate Professor
Department of Mining Engineering
National Institute of Technology
Rourkela – 769008

ACKNOWLEDGEMENT

I wish to express my profound gratitude and indebtedness to my supervisor **Dr. H. B. Sahu**, Associate Professor, Department of Mining Engineering, NIT, Rourkela; for introducing the present topic and for his inspiring guidance, constructive criticism and valuable suggestion throughout the project work.

I am also giving thankful to all faculty members and staff of Mining Engineering Department, NIT Rourkela. My special thanks go to Mr. B.N. Naik, Mr. B. K. Pradhan, Mr. Soma Oram and Mr. B.K. Bhoi for their help in carrying out different experiments in the solid fuel technology laboratory and mineral processing laboratory. I also express my sincere thanks to Mr. Anubhav Gaurav and Mr. Snehendra Kumar Singh, Management Trainees at Central Coalfields Ltd. for extending their help in collection of coal samples.

I am thankful to my parents and my brother for their inspiration and moral support. I acknowledge the help and support of my friends for their encouragement and support for my project work.

Last but not least, my sincere thanks to all my well-wishers who have patiently extended all sorts of help for accomplishing this dissertation.

Date: **Santosh Kumar Mirdha**

CONTENTS

ABSTRACT

INTRODUCTION

Coal mine fire is a major problem in India and also worldwide has been a great fear both for the industry and researchers in this field. Most mine fires start very small area by spontaneous heating and gradually enlarge in size, thereby, causing loss of coal, life and also the property, environmental pollution due to emission of gases, damage of machinery present inside the mine, a lots of smoke comes out from the mine, increase of temperature inside the mine and ventilation problems. Therefore, the determination of susceptibility of coals to spontaneous heating and their classification is essential to plan the production activities and optimise coal mine production within the incubation period for proper working. The spontaneous heating of coal may define as, when coal is exposed to air, it absorbs oxygen from air at the exposed surfaces. Some fraction of the exposed coal substance absorbs free oxygen at a faster rate than others and the oxidation process results in the formation of gases, (mainly CO, CO_2), water vapour along with the evolution of some heat during the chemical reaction. The oxidation process of coal takes place even at ambient temperatures.

EXPERIMENTAL INVESTIGATION

The project deals with the proximate analysis and susceptibility indices analysis of several of coal with the spontaneous heating tendency of coal according to the standardised procedure. For this project, 19 coal samples were collected from South Eastern Coalfields Limited (SECL), Bharat coaking coal Limited (BCCL), central coalfields Limited (CCL), North Eastern Coalfields Ltd (NEC), Eastern coalfields Ltd (ECL) of Coal India Limited and Jindal. The intrinsic properties as well as susceptibility indices of the coal samples were determined by following experimental techniques:

- Proximate analysis
- Calorific value
- Wet oxidation potential
- Differential thermal analysis

The project deals with correlation analysis of various parameters determined by experimental techniques like proximate analysis and spontaneous indices.

Table 1 Results of proximate analysis, characteristic temperature and EMF value

Sl. No.	Sample	M (%)	A (%)	VM (%)	FC (%)	Tc (^{0}C)	EMF (mV)
1.	BCCL-1	1.495	13.455	22.155	62.895	249.58	21.5
2.	BCCL-2	1.845	20.19	21.62	56.245	255.72	33.7
3.	BCCL-3	1.94	23.59	24.555	49.915	257.30	50.8
4.	BCCL-4	3.095	18.975	24.81	53.12	227.37	79.5
5.	CCL-1	1.945	28.685	20.425	48.945	252.11	47
6.	CCL-2	1.84	25.56	24.035	48.565	244.08	42.5
7.	CCL-3	2.24	43.13	22.135	32.494	244.70	44.6
8.	CCL-4	2.29	36.415	19.41	41.885	253.04	66.5
9.	JSPL-1	10.83	33.48	23.25	32.44	166.74	149.2
10.	JSPL-2	6.39	50.12	19.41	24.08	205.05	153.2
11.	JSPL-3	11.84	11.38	31.9	44.88	190.33	142
12.	NEC-1	6.05	2.29	41.72	49.94	211.34	114.8
13.	NEC-2	7.29	3.8505	26.943	61.916	211.82	138
14.	ECL-1	5.441	34.58	23.064	31.474	186.49	162.9
15.	SECL-1	4.852	16.9	21.846	56.402	183.84	149
16.	SECL-2	6.691	24.425	23.097	46.787	182.73	146.7
17.	SECL-3	4.947	8.986	23.605	62.48	190.59	147.3
18.	SECL-4	8.316	15.127	18.247	58.31	174.14	150.5
19.	SECL5	5.244	8.529	22.314	63.91	173.23	158.3

CONCLUSION

From the experimental investigation it was found that the coal samples from SECL were very highly susceptible to spontaneous heating, whereas the samples from BCCL and CCL were found to less susceptible to spontaneous heating. It is hoped that the outcome of the project work will help the practicing field engineers to plan their workings in advance so that spontaneous heating of coal leading to mine fires can be avoided.

REFERENCES

Banerjee, S.C. Spontaneous Combustion of Coal and Mine Fires, Oxford & IBH Publishing Co, 1985, Pp. (1-40).

Ramlu M. A. 2007, "mine disasters and mine rescue", 2nd edition, chapter-1, "mine fires" Pp. (2-15).

LIST OF TABLES

LIST OF FIGURES

Chapter-01

INTRODUCTION

- **GENERAL**
- **OBJECTIVE**

Chapter-01

1. INTRODUCTION

1.1. GENERAL

Coal is one of the primary sources of energy, accounting for about 69% of the total energy consumption in our country. India has a good reserve of coal of different grade and lignite. As on 31.03.11 the estimated reserves of coal was around 286 billion tones, an addition of 9 billion over the last year. Coal deposits are mainly limited to eastern and south central parts of our country. The states like Jharkhand, Orissa, Chhattisgarh, West Bengal, Andhra Pradesh, Maharashtra and Madhya Pradesh account for more than 99% of the total coal reserves in our country. The total estimated reserve of coal in India as on 31.03.10 was around 277 billion tonnes. There has been an increase of 3.1% in the estimated coal reserves during the year 2010-11 with Madhya Pradesh accounting for the maximum increase of 5 %. The estimated reserve of lignite as on 31.03.11 was 41 billion tonnes, of which 80 % was in the southern State of Tamil Nadu area. The increase in the estimated reserve of lignite during the year 2010-11 was 2.4%, Tamil Nadu accounting for the maximum increase of 2.7%. India now ranks 3rd amongst the coal producing countries in the world. About 89% of the total coal production in the country produced by various subsidiaries (a total of 470 mines) of Coal India Ltd. and produced up to Dec. 2010 is 299.52 million tonnes (MT).

Coal mine fire is a major problem in the coal mining industry worldwide. It has been reported that majority of fires existing today in different coalfields are mainly due to spontaneous heating of coal. Coal fires in China burn a figured 120 million tons of coal a year, emitting 360 million metric tons of CO_2, amounting to 2-3% of the annual worldwide production of CO_2 from fossil fuels (http://en.wikipedia.org/wiki/Coal). Spontaneous heating of coal is the process of self-heating resulting eventually in its ignition without the application of external heat. When coal is exposed to air, it absorbs oxygen at the exposed surfaces. Some fraction of the exposed coal substance absorbs free oxygen at a faster rate than others and the oxidation results in the formation of gases, mainly CO, CO_2, water vapour along with the evolution of some heat during the chemical reaction. The process takes place even at ambient temperatures. If the rate of dissipation

of heat is slow compared with the evolution of heat by oxidation, there is a gradual build-up of heat and temperature reaches the ignition point of coal which causes of open fire.

Spontaneous heating of coal inside a mine creates a lot of problems viz. loss of coal; accident resulting in loss of lives and property, subsidence, environmental pollution due to emission of gases, damage of machinery present inside the mine, roof fall, damage to the support systems and roadways such as haulage systems etc. In India, as of 2010, 68 fires were burning beneath a 58-square-mile (150 km^2) region of the Jhairia coalfield in Dhanbad, Jharkhand. This region has been hit by the unique phenomenon of mine fires which started in 1916 and is rapidly destroying the only source of prime coking coal in the country. Therefore a lot of research has been and is being carried out to understand the exact mechanism behind spontaneous heating of coal and to assess it accurately. Different methods have been adopted by various researchers of the world to find out the susceptibility of coal to spontaneous heating. A number of experiments have been done for evaluating the spontaneous heating susceptibility of coal viz., Crossing point temperature method (Panigrahi, et al. 2005), Wet oxidation potential method (Tarafadar et.al.1989), Differential thermal analysis (Gauws and Wade, 1989; Pal and Sahu, 1998, Panigrahi et al, 2004), Differential Scanning Calorimetry Technique (Sahu et al., 2005, Mohalik et. al. 2009) and Critical Air Blast (Sahu et.al. 2005).

It is a well-established fact that spontaneous heating of coal depends mainly on two types of factors, such as intrinsic and extrinsic. The intrinsic parameters are mainly associated with the nature of the coal, i.e. its physico-chemical characteristics, petrographic distribution and mineral make up. On the other hand, the extrinsic parameters are related to atmospheric, geological and mining conditions prevailing during extraction of coal seams and these are mainly site specific and difficult to determine.

In the present work, an attempt has been made to assess the role of the intrinsic factors in the spontaneous heating of coal; so that advance precautionary measures can be adopted for the coal seams which are more susceptible to spontaneous heating in the planning g stage it so that the problems of fire and consequent losses can be avoided.

1.2. OBJECTIVE

In order to assess the role of intrinsic parameters in the spontaneous heating of coal; the work was planned with the following objectives:

- Literature review – Collection of all the past works done by various authors both National and international as well as earning information on the topic.
- Collection of coal samples from different coalfields of the country.
- Determination of intrinsic properties of the collected coal samples by carrying out proximate analysis and calorific value tests.
- Assessment of spontaneous heating susceptibility of the collected coal samples by differential thermal analysis and wet oxidation potential analysis
- Assessment of the role of intrinsic parameters in the spontaneous heating of coal by carrying out correlation studies.

Chapter-2

LITERATURE REVIEW

Chapter-2

2. LITERATURE REVIEW

The following is the brief review of the work carried out by different researchers to determine the susceptibility of different coal towards spontaneous heating of coal samples.

Bhattacharyya et al. (1971) carried out laboratory experiments to evaluate the rates of heat exhaust from different coals by a calorimeter during sorption of water vapour in isothermal conditions. It was found that the rate of heat generation in a particular coal increases with the equilibrium humidity insufficiency of the coal, i.e. with the difference of equilibrium humidity of air and coal. For a given coal, the rate of heat propagation due to oxidation had been found to be negligible in comparison with that due to sorption of water vapour. A small peak,, at the starting of the rate curves observed during the tests with dry coals, with the exclusion of anthracite; accounts for this phenomenon had been assayed. The results also showed that under a given test condition the characteristic rate of heat release was dependent on the type of coal, its particle size and its weathering.

Marinov (1976) researched on interaction of lignite, brown and black coal with molecular oxygen by simultaneous TG and DTA. He carried out all his experiments in air. Two programs of controlled heating were used and found that self-ignition occurred only in thick layers. The free surface remaining the same, an equal relative loss in weight of lignite and of brown coal powders respectively was found in the range 200-280°C for layers of different thickness when self-ignition does not occur. Endothermic zones were established in the oxidation of thin layers. Reactions of elimination and hydrogen peroxide formation were held responsible for the endothermicity in some stages of interaction. He also established the changes in weight under conditions where self-ignition occurs and when this critical phenomenon does not take place. Then, he observed a total conversion of coal into gaseous products under a regime of weak exothermicity. He also studied the rate of reactions between porous substances and gases in which the layer thickness was variable.

Riley et al. (1987) examined the factors which contribute to the self-heating of coal in barges. A data bank containing analytical data and barging information on 2283 barges was used to help identify the principal factors contributing to the self-heating of barged coal. Barging studies to examine coal handling and barging techniques designed to

minimize the occurrence of self-heating were conducted. They noticed that a no. of factors including intrinsic properties such as rank, heat of wetting, porosity, exposed surface area, ash content, content of pyrites and other sulphur containing species, hardness, methane content, and thermal conductivity of the coal affect the spontaneous heating of coal. They also observed that Handling conditions that may contribute to coal self-heating include changes in moisture content of the surrounding environment, large variations in the temperature when the coal is shipped, and to the movement of air through the coal.

Tarafdar et. al., (1987) carried out wet oxidation of coal using alkaline permanganate solution and observed the potential changes between a saturated calomel electrode and a carbon electrode immersed in the coal oxidant mixture within a definite reaction time at a constant temperature. The measurements were made on seven coal samples coalfield of known crossing point temperatures (CPT). Four samples, considered to be highly susceptible to spontaneous heating, had CPT in the range 132-137^{0}C, and three, considered poorly susceptible to spontaneous heating, had CPT values in the range 162-168^{0}C, showing two distinct zones of correlation between CPT values and the corresponding differential peak temperatures, and between CPT and the observed potential changes. It was suggested that differential temperature and potential difference measurements during wet oxidation of coal may be used as alternative techniques for the assessment of tendency to spontaneous heating.

Gouws et.al., (1988) gave three characteristics on a differential thermal analysis thermo gram (i.e., the crossing-point temperature, stage II exothermicity gradient and the transition temperature to high-level exothermicity) are generally believed to be indicative of the self-heating propensity of coal. A new index was developed and applied to 58 coals, enabling known dangerous and safe coals to be identified.

Defaveri et al. (1989) carried out **t**heoretical and experimental studies on the propagation of heat inside coal deposits and consideration on the mechanism of spontaneous oxidation of coal at a low temperature. Because, the phenomenon of self-ignition is played an important role in the design of coal storage piles at mine side. They introduced a theoretical model is presented, validated by experiments, for the forecasting of heat diffusion values inside coal piles related to the apparent stocking density. They also tried

to present a forecast model for the trend in the variation and propagation of the temperature inside a coal piles subjected to a spontaneous or accidental generation of heat.

Banerjee et al. (1985) studied the advantages and disadvantages of different fire indices in common use, such as CO/O_2 deficiency (def.) %, CO_2/O_2 def. % and CO/CO_2 percentage, as well as those proposed in the literature such as the disappeared hydrocarbon index, the CO residual gas relationship and the C/H ratio of the products of combustion, are discoursed in terms of their applicability for finding the extent and intensity of underground sealed fires. Five cases of different types of fires were studied and verified using the above indices. The depiction of fires should be made from fire indices, such as the C/H ratio, CO/O_2 deficiency percentage and the CO/CO_2 percentage, temperature profile studies, pressure differential measurements in stopes and spontaneous heating characteristics of the coal concerned in relation and that inferred from other mining factors. The initiation of active fires are declarative upon the values of C/H ratio above 3 or 4, values of the CO/O_2 deficiency percentage of > 0.5 and values of CO/CO_2 of > 2. A C/H ratio of 20 shows a dazzling fire where the possibilities burning of wooden props.

Ogunsola and Mikula (1990) evaluated the spontaneous combustion characteristics of four Nigerian coals of varying rank. They used Crossing point temperature (CPT) and liability index for the four coals for determine of spontaneous combustion characteristics. The CPT was found to decrease with increase in coal rank. The liability index, which gave a better evaluation of susceptibility of coal to spontaneous heating, was also found to decrease with increase in rank and with decrease in oxygen content and moisture holding capacity of the coal.

Jones and Vais (1991) used the activation energy of ignition and thermal diffusivity to measure self-heating of coal for three different Thai lignites and for a sample of Australian lignite for comparison. Activation energies of the order of 10^2kJ mol^{-1} are reported with some spread evident. Thermal diffusivities of the order of $2 \text{ x } 10 \text{W}^{-7} \text{m}^2 \text{s}^{-1}$ are also reported and are compared with existing values for related materials.

Carras and Young (1994) studied the status of self-heating of coal and coal mine waste dumps and observed that the phenomenon of self-heating of coal is the result of several complex physical and chemical processes. From their study of different self-heating

models, they pointed out that that actual test of any model is the extent to which its predictions match actual stockpile behavior. They also suggested that due to the heterogeneous nature of coal there is a need to measure properties such as the oxidation rate, heat of oxidation, heat of sorption, thermal diffusivity and permeability of the coal matrix. Also the effect of particle size and moisture content on the oxidation rate of the material being studied (e.g. coal, char or waste material) needs to be resolved.

Bhatt et, al. (1996) developed a reaction-diffusion approach to consider the effects of moisture evaporation and condensation on the rate of oxidation of coal. For a single isothermal particle, pseudo-steady-state balances on moisture and oxygen permit calculation of the effect of different levels of coal-bound moisture on the rate of oxidation. It was shown that partial wetting of coal or condensation of moisture exerts two competing influences on the overall rate of oxidation. On the one hand, a portion of the coal fills up with liquid moisture; in this region, the rate of oxidation becomes negligible, since the oxygen has to dissolve in the moisture before it can gain access to an active site on the coal surface and the solubility of oxygen in water is low. On the other hand, condensation also leads to the release of the latent heat of vaporization. This heat effect raises the temperature of the particle and increases the rate of oxidation in the dry region of the coal. The relative magnitude of the rates of these competing influences determines whether the potential for spontaneous combustion is abated or enhanced.

Carras et al (1997) extended the CSIRO mathematical model of self-heating (SPLGOF) to predict self-heating in spoil piles. In addition, two small spoil dumps were constructed at a Hunter Valley mine and instrumented with temperature and oxygen probes. The material comprising the dumps was subjected to laboratory oxidation rate measurements so that its reactivity could be quantified. One of the dumps underwent self-heating and provided the opportunity to compare directly the predictions of the CSIRO model of self-heating with measurements of the temperature and oxygen profiles. Allowing for the approximations necessary to run the model, the model predictions were in good agreement with the data from two of the probes but not the third, indicating that while considerable progress had been made in the modelling of self-heating there were still mechanisms which needed to be included.

Kaymakci et, al. (2002): They used linear and multiple regression analyses to determine the relationship between spontaneous combustion parameters (derived from time

temperature curves obtained from laboratory tests) and coal parameters (obtained from proximate, ultimate and petrographic analyses). The linear regression analyses have shown that ash (A), volatile matter (VM), carbon (C), hydrogen (H), exinite (E), inertinite (I) and mineral matter (MM) are the major factors that affect spontaneous combustion.

Panigrahi and Sahu (2003) applied adaptive resonance theory of artificial neural networks (ANN) for classification of coal seams with respect to their proneness to spontaneous heating. They used 31 coal samples from different Indian coalfields covering both fiery and non-fiery coal seams of varying ranks spreading over 8 different mining companies. The intrinsic properties of these samples were determined by carrying out proximate, ultimate and petrographic analyses. The susceptibility indices of these samples were studied by five different methods, viz. crossing point temperature, differential thermal analysis, critical air blast analysis, wet oxidation potential difference analysis and differential scanning calorimetric studies. They carried out exhaustive correlation studies between susceptibility indices and the intrinsic properties and observed that the constituents of proximate analysis had a better correlation with the spontaneous heating susceptibility potential of coal seams than other intrinsic properties. They used moisture, volatile matter, ash along with the spontaneous heating susceptibility indices obtained by CPT, DTA, DSC and wet oxidation potential analysis; as inputs and classified the coal seams into four different categories.

Sahu et al. (2004) applied the differential scanning calorimetry (DSC) experimental method to find out the spontaneous heating susceptibility of coal samples. They also examined the crossing point temperatures (CPT) of all the samples for a comparative study. They concluded that differential scanning calorimetry predicts the spontaneous heating susceptibility more accurately than crossing point temperature for the coal samples studied in their investigation and suggested that the onset temperature obtained from differential scanning calorimetry may be a better method than crossing point temperature.

Sahu, et al. (2005) Described the determination of spontaneous heating susceptibility of coal samples by Critical Air Blast (CAB) rate for assessing the proneness of coal to Spontaneous heating. They carried out the experiment on 31 coal samples from different Indian Coalfields. They also compared the results with that of crossing point temperature of that all samples and suggested that the critical air blast rate prediction is more useful then crossing point temperature.

Beamish and Arisoy (2008) developed a database of coal self-heating rates under adiabatic conditions at The University of Queensland. They tested Coals from Australia (Queensland and New South Wales), New Zealand (North and South Island), Indonesia and USA. As a result of their work, they established relationships and established trends for the effects of various intrinsic coal properties on self-heating rates and also identified anomalous coals. They observed the self-heating of coal was due to a number of complex exothermic reactions. Coal would continue to self-heat provided that there is a continuous air supply and the heat produced is not dissipated. These results showed coal quality trends that can be used to infer R70 values for coals with no previous testing history. They concluded significant relationships exist between coal self-heating rate and intrinsic coal properties of coal rank, mineral matter composition and coal type. They observed that the relationship with coal rank was non-linear and could be expressed in the form of a third order polynomial for coals ranging in rank from sub-bituminous C to low volatile bituminous.

Yuan and Smith (2008) carried out a computational fluid dynamics (CFD) study to model effects of coal properties on the potential for spontaneous heating in long-wall gob (mined out) areas and simulated two long-wall panel districts using a bleeder ventilation system. The permeability and porosity profiles for the long-wall gob were generated from a geotechnical model and were used as inputs for the three dimensional CFD modelling. The spontaneous heating is modelled as the low temperature oxidation of coal in the gob using kinetic data obtained from previous laboratory scale spontaneous combustion studies. Heat generated from coal oxidation was dissipated by convection and conduction, while oxygen and oxidation products were transported by convection and diffusion. Unsteady state simulations were conducted for three different US coals and simulation results were compared with some available test results. The effects of coal surface area and heat of reaction on the spontaneous heating process were also examined. They observed that coals have different self-heating potentials based on their minimum self-heating temperatures (SHTs) and found that a coal with a larger minimum SHT would result in longer induction time for spontaneous combustion.

Mohalik, et al. (2009) presented the review of application of three thermal techniques viz; differential thermal analysis (DTA), thermogravimetry (TG) and differential scanning

calorimetry (DSC); for studying the susceptibility of coal to spontaneous heating and fire. They critically analysed the experimental standards adopted by different researchers, while applying these techniques in studying thermal behaviour of coal samples. They determined the knowledge gap in this research area, which could be taken up for effectively applying these techniques for assessing the disposition of coal to spontaneous heating.

De-ming et al. (2009) carried out oxidation kinetics test method for assessing the propensity of coal to spontaneous combustion was studied in their paper. According to them the existing test methods only embody the characteristics of one stage rather than the whole spontaneous combustion process. They opined that spontaneous combustion of coal is a non-linear and kinetic process which can be divided into several stages and the reaction kinetics of coal in different stages differs greatly. Therefore, just using the characteristics of only one stage to evaluate the whole coal oxidation process is not comprehensive. They proposed a new standard for classification of the propensity of coal to spontaneous combustion. They selected two parameters for different oxidation stages and the comprehensive oxidation kinetics determination index for coal.

Sahu et al. (2009) used the k-means clustering approach for classification of coal seams with respect to their spontaneous heating susceptibility. They collected a number of coal samples of varying ranks from different coalfields of the country. They determined the intrinsic properties of the coal seams by proximate, ultimate and petrographic analyses. They also studied the spontaneous heating processes of the samples using different experiments in the laboratory, viz. crossing point temperature, differential thermal analysis, critical air blast test and differential scanning calorimetry. Again they carried out correlation studies between the intrinsic properties and susceptibility indices to identify the parameters for clustering purposes. Using the identified parameters and the k-means clustering algorithm, they classified the coal seams into four different categories.

Lang and Fu-bao (2010) collected related data cited from the latest studies on spontaneous combustion research from around the world, and selected those which were applicable to the evaluation of Chinese collieries. Based on that data, they reconsidered the factors leading to spontaneous combustion, and integrated all the new found factors into a comprehensive coal fire hazard assessment system which was conducive to both prediction and management. Applying holistic scoring method and analytic hierarchy process, they integrated all the factors into a quantitative model, and classified the ratings

into five levels. They developed user friendly application software that assists the evaluators and simultaneously offered reliable recommendations for the prevention of fires. They tested three domestic colliery cases with varying fire hazards and through practical application, they showed that the hazard evaluations proved to be objective and valid and so recommended the system for Chinese coal mines.

Xie et al. (2011) observed that ethylene could be used as an important index gas, but is only generated when coal reaches a characteristic temperature. Due to dilution of ventilation air and detection limits of the instruments used for gas analysis at coal mines, ethylene is not normally detected until a spontaneous heating has developed past its early stage, hence missing an optimum opportunity for mine operators to control potential hazards. To address the issue, they developed an ethylene enriching system (EES), based on its physical adsorption and desorption properties, to significantly increase ethylene detection sensitivity in mine air. They applied the EES in a number of underground coal mines in China to detect the occurrence of spontaneous combustion at its early stage. They suggested that the EES could be used in conjunction with other index gases such as carbon monoxide and hydrogen for early spontaneous combustion detection, providing mine operators with precious time required to implement effective spontaneous combustion control measures.

Chapter-3

SPONTANEOUS HEATING OF COAL

- **DEFINITION**
- **MECHANISM OF SPONTANEOUS HEATING OF COAL**
- **FACTORS AFFECTING SPONTANEOUS COMBUSTION OF COAL**

Chapter - 3

3. SPONTANEOUS HEATING OF COAL

3.1. DEFINITION

Spontaneous heating is called as "self-heating of coal ensuing in its ignition without the application of external heat". The phenomenon in which the coal catches fire automatically on coming in contact with oxygen in that atmosphere without any external source of fire which leads to mine fires is known as spontaneous heating of coal. It is primarily thought that the main causes of spontaneous heating the self-oxidation of coal. The heat generated from spontaneous heating, if absorbed by surrounding then the phenomenon is called low temperature oxidation. However, if the heat is not removed then there will be progressive rise in temperature resulting in spontaneous combustion and open fire.

Coal fires require three basic elements to exist as shown in figure 3.1.

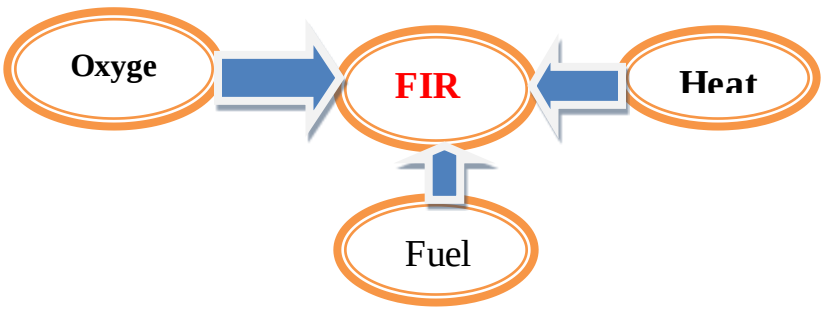

Figure-3.1.: The Fire Traingle

The process leading to spontaneous combustion can be summarised as follows:

- Oxidation occurs when oxygen reacts with the fuel, i.e. coal.
- The oxidation process produces heat.
- If the heat is dissipated, the temperature of the coal will not increase.
- If the heat is not dissipated then the temperature of the coal will increase.
- At higher temperatures the oxidation reaction proceeds at a higher rate.
- Eventually a temperature is reached at which ignition of the material occurs.

3.2 MECHANISM OF SPONTANEOUS HEATING OF COAL

The development of self-heating requires a large surface area of crushed material combined with a slow migration of air through that material. Hence, the problem arises in goaf (gob) areas, caved zones, crushed pillar edges, fractured coal bands in roof or floor strata, stockpiles and tips on surface, and within abandoned sections of mines. The oxidation of coal, like all oxidation reactions, is exothermic in character. The progressive stages of spontaneous combustion appear to be complex and not yet fully understood.

However, scientists agree that the nature of the interaction between coal and oxygen at much low temperatures is amply physical (adsorption) and changes into a chemisorption form commencing from an ambient temperature. When coal is exposed to air it occupies oxygen at the exposed surface area. Some fraction of the exposed coal substance absorbs oxygen at a faster rate than others and the oxidation results in the establishment of gases. Mainly CO, CO_2, water vapour along with the development of some heat during the chemical reaction of that. The rate of oxygen ingestion is extremely high during the first few days (particularly the first few hours) following the vulnerability of a fresh coal surface to the atmosphere. It then decreases very tardily without causing problems unless rendered heat is allowed to gather in the environment. Under certain statuses, the accumulation of heat cannot be precluded, and with sufficient oxygen (air) supply, the operation may reach higher stages. The CO, CO_2 and H_2O molecules are disintegrated above 70-85^{0}C at initial stage to form the loose coal oxygen water complex.

The rate of chemical reactions and exo-thermicity change with the rise in temperature, and radical changes take place, starting at about 100^{0}C, mainly due to loss of moisture. This process continues with the-ascend in temperature, yielding more stable coal-oxygen complexes until the critical temperature is reached. The ignition temperature of bituminous coal is nearly 200^{0}C and of anthracite coal nearly 398^{0}C. A good air current will effectively prevent oxidation. Once the coal reaches it ignition point, the air supply to it will only increase the combustion. The term spontaneous combustion express a relative value which are separated as highly susceptible or not.

Whenever a combustible material and oxygen are in contact, an oxidation reaction occurs and heat is released. The same comment can be made for any fuel/air mixture. At normal

ambient temperatures, the reaction is so slow that it can be completely missed. However, if the temperature (T) is increased, the rate of reaction increases exponentially, i.e.

$$\text{Rate of reaction} = c_f . c_0 . A^{\frac{-E}{RT}}$$

where: - c_f and c_0 are the concentrations of fuel and oxygen respectively

- A is the pre-exponential factor
- E is the activation energy for the reaction
- R is the ideal gas constant

(see also the appended list of symbol)

The form of equation indicates a doubling of the rate for each 10^0 C rise in temperature.

Various stages of coal oxidation are given in the flow chart below:

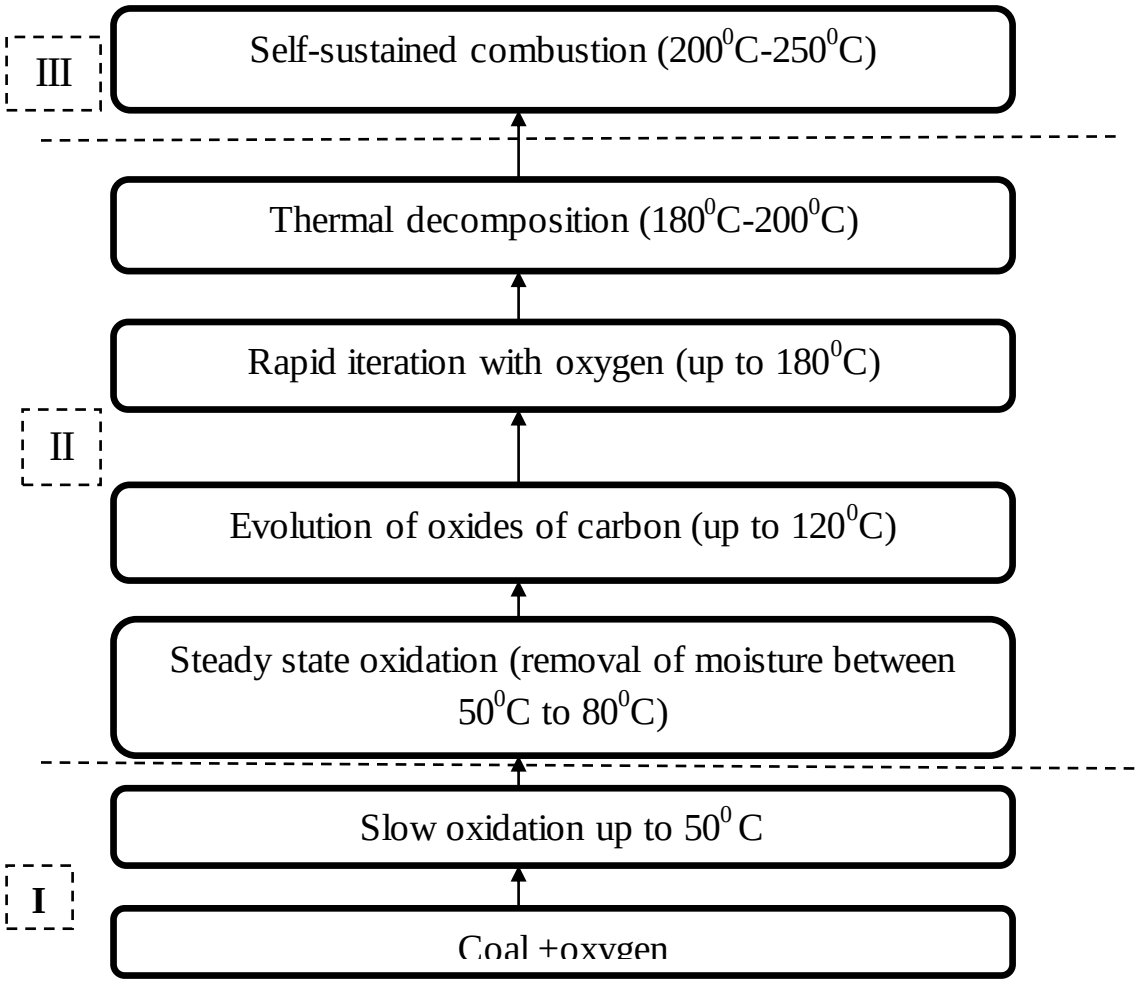

Fig 3.2 Stages in the spontaneous heating of coal (Banerjee et.al., 1985)

3.3. FACTORS AFFECTING SPONTANEOUS COMBUSTION OF COAL

The main reason for the difficulties in understanding the mechanism of spontaneous combustion is the presence of many internal and external factors affecting the initiation and development of the phenomenon.There are many factors which affects the spontaneous heating of coal in both internally and externally. These factors are mainly dividing in 3 types and that are given below:

3.3.1. Mining Factors

1) Mining Methods
2) Rate of Advance
3) Pillar Conditions
4) Roof Conditions
5) Crushing
6) Packing
7) Ventilation system and air flow rate
8) Roadways
9) Leakage
10) Multi Seam Workings
11) Coal Losses
12) waste material in abandoned areas
13) Change in Humidity
14) Heat from Machines
15) Stowing
16) Effect of Timber
17) Barometric Pressure
18) Worked-out areas
19) Oxygen concentration

3.3.2. Seam Factors

1) Rank of coal
2) Petrographic Composition
3) Moisture
4) Thermal Conductivity
5) Particle Size/Surface Area
6) Temperature
7) Bacteria
8) Ash/Mineral Matter
9) The effect of previous oxidation or heating
10) Physical Properties
11)Heating due to earth movement
12) Sulphur
13) Pyrite Content
14) Available air

3.3.3. Geological Factors

1) Seam thickness
2) Seam gradient
3) Coal Outbursts
4) Geothermal Gradient
5) Caving characteristics
6) Faulting
7) Depth of cover
8) Coal Friability

3.3.4. Other factors

1) Methane contents
2) Oxygen concentration

3) Excavation stability and maintenance 4) Chemical constituents

3.3.1. Mining Factors:

3.3.1.1. Mining methods: Partial pillar extraction underground mining methods, in which part of the coal seam is left in the goaf and in pillars, can contribute to the potential for spontaneous combustion. This may have relevance to the mining of old workings, since surface mining will expose areas where crushed coal has been left for long period that also be a cause of spontaneous heating. An advancing method of mining on the long wall system leaves extracted areas lying between the entries serving the working places. The ventilating pressure differences will encourage air to flow across these areas, with the accompanying risk of combustion. In high-risk situation a retreating long-wall system of working is normally preferred. However, the most important advantage gained by adopting a retreating system is lost if an attempt is made to ventilate the waste using a homophile entry system.

3.3.1.2. Rate of advance: The rate of advance of the mining is also causing spontaneous heating problem. In practice, when a working face is operating normally, any individual piece of coal passes through the zone at a rate equal to the rate of advance of the working face. It is the time taken from entering or leaving the zone that is critical. If the time is excessive, the oxidation may occur to an unacceptable degree and a gob fire could result.

***3.3.1.3. Pillar conditions*:** Pillar conditions mean mainly refer to pillar size and strength. It has a direct influence on the liability to spontaneous heating. Ideally, pillars should be of a size to avoid crushing. This size depends on the strength of the coal, the depth of the cover and the influence of other workings within the locality or panel. Increase in methane emission is an indication of crushing, around pillars that subsequently spontaneously heated.

3.3.1.4. Roof conditions: Poor roof releases the shock waves to pass through easily and the developments of cracks increases inside the roof and that causes to spontaneous heating. Poor roof conditions increase the liability to spontaneous combustion. These falls leave cavities which have to be supported and are often filled with timber. Also due to their nature, these areas constantly fill with methane and ignition often results to spontaneous heating. So, better roof condition gives no spontaneous heating property.

3.3.1.5. Crushing: Pillar crushing is a major problem to spontaneous heating. Where a pillar is subjected to crush, a situation can develop where leakage paths are created,

lending both to the flow of air into the coal and, in some circumstances, through the solid to affect a more distant zone. Due to crushing of pillars, loose coal is usually present in worked out areas, and is produced either by pillar spalling or by roof collapses with associated sluggish ventilation. These areas are predominantly spontaneous combustion hazards to the mining area.

3.3.1.6. Packing: Where packs are used in seam, coals are more liable to spontaneous combustion. According to the different study it has shown that they must be of the highest possible quality to spontaneous heating.

3.3.1.7. Ventilation system and air flow rate: Air flow rate is a complex factor because air provides oxygen while it also carries away the heat produced. There is a critical air quantity that supplies sufficient oxygen to allow the coal to oxidize but is insufficient to prevent the generated heat from accumulating.

3.3.1.8. Roadways: Due to proper roadways, the atmospheric pressure and temperature conditions because of air moving in and out of coal seams is changing. This is of particular relevance when old workings are exposed by surface mining.The risk increases with thickness of coal, as this increases the area of coal exposed.

3.3.1.9. Leakage: To generate the circumstances in which spontaneous combustion can occur, there must be a supplying of oxygen and a situation where a built-up of heat is possible. This can be brought about by air escapes through fissures in solid coals and result in a shallow seated heating .this situation can happen where leakage paths exits at air crossings, in and around regulators and doors, and other similar locations where outflow there is a high pressure gradient and propensity for air to attempt to flow through solid coals.It is not feasible to rely on making stoppings impermeable and if they were completely impermeable a dangerous pressure of firedamp could be seen accumulating.

3.3.1.10. Multi seam workings: Due to multi seam workings, one seam is working above or below of other seam which may or may not in working condition. So, spontaneous heating develops for roof condition, leakage of air etc. Where a multi-seam situation exists, both during the working of the first seam and of subsequent seams, conditions can arise with spontaneous combustion hazards for the seam currently being worked and any other seam above or below of it.

3.3.1.11. Coal losses: Coal losses – that is, leaving remnant coal in worked-out areas – are a serious heating hazard, and most gob fires result from this factor. There is no normal mining system that can guarantee that remnants will never be left in a waste area. Most mining systems result in a significant loss of coal. The resulting situation, in which the coal is frequently likely to be crushed, finely divided, and in a location where build-up is possible must be considered a potential hazard.

3.3.1.12. Waste material in abandoned areas: The timber props left in the waste caused the coal roof to disintegrate and created a saving thus encouraging the spontaneous heating of coal. Presence of timbers in the mines leads to the danger of catching of fire which gives the heat required for spontaneous heating of coal.

3.3.1.13. Change in humidity: If coal absorbs moisture from the ventilation air it will heat up due to the release of the latent heat of condensation and chemisorption effects. On the other hand, if the coal loses water by evaporation to the ventilation air, the reverse occurs. Both effects will occur if there is any unbalance between moisture in the coal and moisture in the air. The balance between the complex mining conditions that can bring about condensation or evaporation has not fully been researched Nevertheless it is becoming increasing patent that changes in environmental moisture play a significant role in leaning the balance between adsorption and heating and evaporation and cooling.

3.3.1.14. Heat from machines: Normally heat from machine is dissipated within the ventilating air stream and the temperature rise of the general body of the air is likely to be very small. In some circumstances, the effect of the heat from machines is secondary, in that additional air may have to be circulated and will require a higher ventilating pressure with consequent increase risk of leakage.

3.3.1.15. Stowing: Stowing is carried out in a no. of coal fields around the worlds specifically in order to seal mined out areas completely. As such, it has proved to be an effective method of spontaneous combustion control.

3.3.1.16. Effect of timber: In the early days of spontaneous combustion generally timber was found at or near the heating in practically every instance and as a result there was thought that was timber was a primary cause of spontaneous combustion. And in case of collapse of any timber inside of working area that causes roof problem and that causes spontaneous heating of coal.

***3.3.1.17. Barometric pressure*:** barometric pressure changes inside the mine due to-continuous leakage resulting from a difference in pressure in the return and intake stoppings, fluctuations in ventilating pressure resulting from the opening of doors and the movement of cages and mine cars. Although leakage is very frequently responsible for starting fresh heating or the winnowing up of old heating, the influence of barometric changes is believed by many to be of predominate importance.

3.3.1.18. Worked-out areas: Worked-out areas which are not sealed by ventilation stoppings are potential sources of spontaneous heating. They are likely to have suspension in the ventilation system as result of roof falls or flour lift tending to impairment in rib condition and the presence of loose, small beat coal contributing to potential combustion.

3.3.1.19. Oxygen concentration: It need not be explained that the volume fraction of oxygen in the gas plays a key role for the rate of the reaction of oxidation. Higher the oxygen concentration in the atmosphere more rapid is the oxidation process as oxygen is readily available. Limiting the supply of oxygen to the active surfaces of the solid matter abates the reaction well.

3.3.2. Seam Factors:

3.3.2.1. Rank of coal: Lower rank coals are more susceptible to spontaneous heating. Generally the rank of a coal depends on the types of the original plant or forest from which it was formed and the amount of change that its organic matter has undergone during the period of formation. And the higher rank coal contents higher percentage of carbon and low percentage of oxygen. The higher the rank, e.g. anthracite, the slower the oxidation process, while lignite of low rank oxidizes so rapidly that is often stated that is cannot be stored after mining without ignition because of the above condition. So,it is widely recognized that lower rank coals are more susceptible to spontaneous combustion than higher rank coals.

3.3.2.2. Petrographic composition: The abnormalities in this relationship may be attributed to the petrographic constituents of coal. However, this phenomenon has not yet been fully understood and requires further study. The National Coal Board carried out a series of oxidation tests on handpicked petrographic constituents from five coals ranging from high ranking coking coal to low rank bituminous coal. Among the petrographic constituents of coal, fusain is the least reactive and durian is more reactive than vitrain.

The general trend also indicates an increase in self-heating propensity with either increasing Vitrinite or Liptinite content.

Liptinite > Vitrinite >> Inertinite

3.3.2.3. Moisture: Changes in moisture content; i.e., the drying or wetting of coal, have apparent effects in spontaneous heating of coal. The effect of moisture on spontaneous heating is uncertain. A small quantity seems to assists rather than slow the heating while large quantities of moisture slow the heating.

On the other hand a promotion of self-ignition by the wetting of materials prone to this has been observed.

Dry coal + moisture → wet coal + heat

3.3.2.4. Thermal conductivity: Due to the conductivity property of coal, heat transfers from one place to other. The conductivity of moist-coal having about 5-7% moisture is at the highest. If the coal is more compact then the conductivity is more and heat changes according to that.

3.3.2.5. Particle size/surface area: A solid coal face generally presents very little danger of spontaneous combustion, partly due to the small surface area and partly due to the very low permeability of solid coal gases. It is however, generally when coal is shattered in mining, or broken by roof pressure, when falls and faulting occur that spontaneous combustion is likely to take place. It is the small size coal that is mainly responsible for the heating. The air passes into the mass oxidizes a little of the coal near the outer surface. They produces a slight rise in temperature, so that as the air penetrates deeper and deeper, it becomes warmer and warmer and although part of its oxygen has been absorbed there is still enough to produce oxidation. Consequently, it is at some distance inside the mass that heating develops most rapidly. It should be noted that a flame is due to the combustion of gas and this requires that a moderately high proportion of oxygen be present. Once the oxidation process has gone beyond the early stages and heat is accumulating, it is only a matter of time before actual ignition takes place.

3.3.2.6. Temperature: Higher surrounding temperature leads to increase in oxidation process and ultimately in spontaneous heating of coal. There is a pronounced temperature

coefficient of oxidation and the average rate of oxidation approximately doubles for every rise of 18 degree Fahrenheit.

3.3.2.7. Bacteria: The contribution of heat due to the action of bacteria cannot be completely ruled out. In fact, spontaneous heating observed in haystacks and in wood are known to be mainly due to bacterial action.It is observed that thiobaccillus ferro-oxidants and ferro-baccillus thio-oxidants are the bacteria which play the role for spontaneous heating of coal.

3.3.2.8. Ash/Mineral matter: Ash content generally decreases the liability of coal to spontaneous heating. Certain parts of the ash, such as lime, soda and iron compounds, may have an accelerating effect, while others, such as alumina and silica, produce a slowing down effect. It is clear that some chemicals promote combustion while others suppress its development. Also, it is known that oil shale bands adjoining coal seams play an important role in mine fires. However, mineral matter may also create obstruction of access to oxidation sites, lowering the self-heating rate of the coal even further.

3.3.2.9. The effect of previous oxidation or heating: A fresh coal is relatively reactive to oxygen than a weathered coal. The ignition temperature of fresh coal is much lower than that of such a weathered coal. On the other hand, a fresh coal which is continuously getting oxidized would ignite at a much higher temperature due to higher oxidation rate provided the heat dissipation is much lower than the heat generation.

3.3.2.10. Physical properties: A number of physical properties such as porosity, hardness, thermal conductivity and specific heat can affect the rate of oxidation of coal. More porous coal tends to higher spontaneous heating of coal.

3.3.2.11. Heating due to earth movement: In site the mine the heat is generated by the movement of the earth. That is the cause of spontaneous heating of coal.

3.3.2.12. Sulphur: It may be relevant to add that the green crystals of ferrous sulphate formed as shown below, often gets neutralised with carbonates of Ca , Mg, or Fe++ present in the coal.

$$2FeS_2 + 7O_2 + 16H_2O = 2H_2SO_4 + 2FeSO_4.7H_2O + 316kcal$$

It observed that Sulphonate coal has greater reactivity towards oxygen, particularly in the presence of iron oxide. They explained the role of pyrite to sulphonate the coal from the liberation ofH_2SO_4, in the presence of moisture.

3.3.2.13. Pyrite content: Heating due to oxidation of pyrites has been known to be a common phenomenon in pyrites mines. It was suspected earlier that heat evolved from aerial oxidation of pyrites is the cause of spontaneous heating of coal. However, it has now been proved that pyrite present in coal might assist the oxidation of its carbonaceous content by breaking down coal into smaller fragments and exposing larger surface area to the air, as well as by elevating the temperature due to heat liberated from its own oxidation.

3.3.2.14. Available air: Where there is a small amount of air, the rate of oxidation is very slow and there is no appreciable rise in temperature. Where there are large quantities of air passing over or through the coal, any heat produced will invariably be carried away so that the temperature does not rise and the oxidation rate remains at a low level.

3.3.3. Geological Factors:

3.3.3.1. Seam thickness: Where the seam thickness is greater than which cannot be mined completely in one part or at a movement, the area is more susceptible to spontaneous combustion, since the un-mined area tends to be subjected to sluggish ventilation flow and free face left. It was found that spontaneous combustion was apparently dependent upon the physical factors involved by the thickness of the seam, the methods of working type of ventilation and the friable nature of the coal. Also, in thick seams certain bands within the section can be more liable to spontaneous combustion than others. The thicker the seam, the more difficult it becomes to avoid leaving relatively high risk coal within the goaf area. In some cases it is necessary to mine the waste. However, leaving the low risk coal in the waste invariably tends to be practically impossible. In certain cases, a coal roof and floor way thus be left where:

1. The natural floor or roof tends to be weak
2. The seam is thick.
3. There are inferior coals over or below the seam.

4. There are inferior coals over or below the seam, in those cases there will undoubtedly be coal in a broken form places where it can heat, and the points of dander presented.

3.3.3.2. Seam gradient: Board & pillar and long wall methods are generally used in flat seams which are less susceptible to spontaneous heating of coal. In an inclined seam control of combustion becomes more complex, since convection current resulting from the difference in the temperature must tend to cause air currents in the goaf. In addition, within the extracted areas, flow may be due to irrepressibility as a result of the differing densities of the methane, carbon dioxide, nitrogen and natural ventilating pressure.

3.3.3.3. Coal outbursts: Coal outbursts usually occur in the harder formations and higher rank coals rather than in the softer and lower rank coals. However, great care must be taken where there is a possibility of coal outburst and spontaneous combustion occurring concurrently, as the danger of the products of an outburst i.e. finely powdered coal and/or methane, passing over the site of an active heating are very great. The incidence of both spontaneous combustion and outburst increases with depth of the coal seam.

3.3.3.4. Geothermal gradient: Geo-thermal gradient doesn't directly affect the heating hazard; however, where geothermal gradients are high, the strata temperature in the workings is likely to increase more rapidly with increasing depth of working than where the geothermal gradient is low. If the seam at higher geothermal gradient zone then the tendency towards spontaneous heating of coal is also high.

3.3.3.5. Caving characteristics: In the mines where partial extraction is practiced, adequate pillars are left to support the super incumbent strata, and the caving characteristics are generally of little significance. In order to reduce the amount of leakage air flow within the extracted areas, it is desirable for waste to be filled with as fine a material as possible .Thus, this material occupies the greatest volume and fills the void without causing spontaneous effects.

3.3.3.6. Faulting: Faulted group frequently has an influence on spontaneous combustion due to some reasons. Any digging action along the fault plane, with the resulting formation of the fine coal and the ventilating air enter with that fault to seam or oxidise that fine coal may leads to spontaneous heating. A fault generally slows down the rate of face advance to a safe minimum, with the incidental risk of heat development.

3.3.3.7. Depth of cover: The depth of cover does not necessarily affect the risk of spontaneous combustion. In general, the greater the depth of cover, the higher the natural strata temperature and thus higher is the base temperature of insight coal. With increase in depth, strata temperature increases with a rate of 40m per 1°C.

3.3.3.8. Coal friability: The more friable the coal is the larger the surface area exposed to oxidation, thus tending to yield more heat per unit volume of coal. The coal is break easily after the extraction of the coal and the surface area also increases according to that. If the surface area is increased then more surface area is exposed to air. So, with the increase of the surface area the spontaneous heating tendency also increases.

3.3.4. Other factors: (Ramlu M. A., 2007)

3.3.4.1. Methane contents: The presence of methane in macro and micro pores of coal inhibits the oxygen access and thus the oxidation process is retarded, particularly, in highly gassy seams. However, as degasification takes place with time, more and more surface becomes available for aerial oxidation. Coals containing less than 5 cubic meters of methane per tons of coal show high rates of oxygen absorption and are more liable to spontaneous heating.

3.3.4.2. Oxygen concentration: The heat generate from coal is from the oxidation of coal in presence of oxygen. It need not be explained that the volume fraction of oxygen in the gas plays a key role for the rate of the reaction of oxidation. Higher the oxygen concentration in the atmosphere more rapid is the oxidation process as oxygen is readily available.

***3.3.4.3. Excavation stability and maintenance*:** It is required to excavation the material in safety way and maintenance of the roadway, machineries used in site the mine and the ventilation also.

3.3.4.4. Chemical constituents: Ash generally decreases liability for spontaneous heating but certain parts of ash such as lime, soda; iron compounds have accelerating effect whereas alumina and silica have retarding effects. Many other chemicals bear upon the rate of oxidation to some extent, either accelerating or preventing it. Alkalis can behave as accelerators, and borates and calcium chloride as retardant.

Chapter-04

EXPERIMENTAL INVESTIGATION

- **SAMPLE COLLECTION AND PREPARATION**
- **METHODS FOR DETERMINING INTRINSIC PROPERTIES OF COAL.**
- **METHODS FOR DETERMINING SPONTANEOUS HEATING SUSCEPTIBILITY OF COAL.**

Chapter-04

4. EXPERIMENTAL INVESTIGATION

In order to find out the role of intrinsic factors in the spontaneous heating of coals a number of samples were collected from different coalfields of the country. The intrinsic properties were determined by carrying out proximate analysis and gross calorific value tests according to the standardised experimental procedure. The spontaneous heating susceptibility of the col samples was studies by differential thermal analysis and wet oxidation potential analysis respectively. The details of sample collection and experimentation have been presented in this chapter.

4.1. SAMPLE COLLECTION AND PREPARATION

Sampling is the process of collecting a small portion of a whole such that the substance of that element represents that of the whole of coal body. It is the process by which physical and chemical features of a mineral or ore are determined with the desired accuracy for calculation. In the case for coal it covers the properties ascertained by proximate and ultimate analysis such as fixed carbon, volatile matter, ash, caking index and calorific value etc. the physical nature of the ore is sometimes requirement to be determined and the sampling process assumed should be able to give this information too. Samples are generally collected at regular interval. The interval of sampling point is regulated by the regularity of the deposits as well as the accuracy for sampling projected.

All the samples were collected following the channel sampling procedure (IS 436 Part I/Section I - 1964). The particular seam sample shall, be taken in a channel representing the total cross-section of the whole seam having the dimensions of 30 x 10 cm, i.e. 30 cm in width and 10 cm in depth. For that purpose there are two parallel lines, which are 30 cm blot out end at right angles to the bedding planes of the seam shall be labelled by a chalked string on the plane, freshly exposed surface of the coal seam. It is Obvious that, dirt bands exceeding 10 cm in thickness shall be neglected because of good result. The channel between the marked chalk lines in the seam shall be cut to a depth of 10 cm and the coal sample collected on a clean strong cloth or tarpaulin placed instantly at the bottom so that the chances of pieces flying off during excavation of coal are understated.

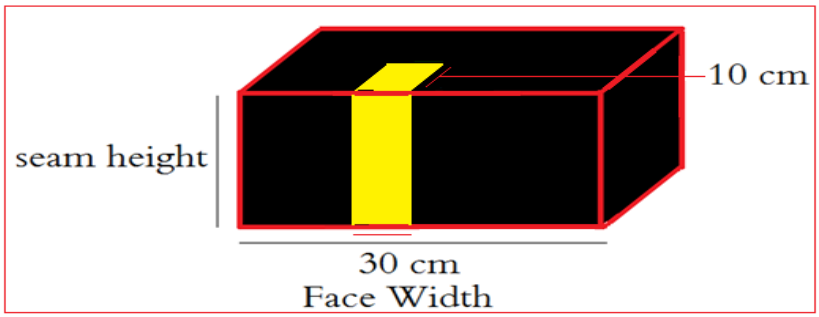

Fig 4.1 Channel Sampling

The samples were taken from the different coalfield by channel sampling are broken in crusher or as per the experimental method necessities in the laboratory. The crushed and grinding sample are then sieved by the different sieve to required sizes which are mentioned in the IS and stored in air tight polythene packets. The packets are then stored in air tight containers for further use in the experiments (IS 436 Part II-1965). The samples are collected from different coalfield of India are given below in table 4.1:

Table 4.1: Details of Coal Samples Collected

Sl. No.	Sample No.	Subsidiary/Company
1.	BCCL-1	Bharat Coaking Coals Ltd.
2.	BCCL-2	
3.	BCCL-3	
4.	BCCL-4	
5.	CCL-1	Central Coalfields Ltd.
6.	CCL-2	
7.	CCL-3	
8.	CCL-4	
9.	JSPL-1	Jindal
10.	JSPL-2	
11.	JSPL-3	
12.	NEC-1	North Eastern Coalfields Ltd.
13.	NEC-2	
14.	ECL-1	Eastern coalfields Ltd.
15.	SECL-1	South eastern coalfields Ltd.
16.	SECl-2	
17.	SECL-3	
18.	SECL-4	
19.	SECl-5	

4.2. DETERMINATION OF INTRINSIC PROPORTIES OF COAL

4.2.1 Proximate Analysis (IS 1350 Part I -1984)

Proximate analysis was developed as a simple mean of determining the distribution of products that are found in coal. When the coal sample is heated under specified conditions, then it classifies the products into four groups: i) moisture; ii) volatile matter iii) fixed carbon, iv) ash, the inorganic residue remaining after combustion. For proximate analysis, i.e. for the determination of volatile matter, moisture, ash and fixed carbon, the method determined by IS (Indian Standard) 1350 (Part- I)-1984 was followed.

Determination of Moisture Content (M)

Coal is always associated with some amount of moisture, which is both physically and chemically bound, due to its nature, origin and occurrence. It is customary to differentiate between extraneous and inherent moisture. When a wet coal is displayed to atmosphere, the external moisture evaporates by sunlight, but the obviously dry coal still contains some moisture, which can be removed only on heating above 100^0C that moisture is called air-dried or hygroscopic moisture. The quantity of external moisture counts mainly on the mode of occurrence and handling of coal, but the air-dried moisture is associated to the inherent hygroscopic nature of the coal.

Experimental Procedure

About 1g of finely powdered (-212μ) air-dried coal sample is weighed in a silica crucible and then placed inside an electric hot air oven (Figure 4.1) maintained at 108^oC. The crucible with the coal sample was allowed to remain in the oven for 1.5 hours and was then taken out with a pair of tongues, cooled in a desiccator for about 15 minutes and then weighed. The loss in weight was reported as moisture (on percentage basis). The calculation was done as per the following.

$$\% \text{ Moisture } = \frac{Y-Z}{Y-X} \times 100$$

Where X = weight of empty crucible, g

Y = weight of crucible + coal sample before heating, g

Z = weight of crucible + coal sample after heating, g

Y - X = weight of coal sample, g

Y- Z = weight of moisture, g

Determination of Ash Content (A)

During the ashing procedure, the coal ash is the residue left after the combustion of coal under defined conditions. It does not occur as such in the coal, but is formed as the result of chemical changes that take place in the mineral matter. Ash and mineral matter of coal are therefore not identical.

Mainly, the extraneous and inherent mineral matters are the two types of ash forming materials in coal. The extraneous mineral matter consists of materials like calcium, magnesium and ferrous carbonates, pyrite, marcasite, clays, shale's, sand and gypsum. The extraneous mineral matter builds on its origin by two types that are given below:

- The substances which got linked with the decaying vegetable material during its transition to coal, which is difficult to remove by mechanical methods,
- Rocks and dirt getting mixed up during mining and handling of coal.

The inherent mineral matter is the inorganic elements combined with organic components of coal. The origin of such materials is likely the plant materials from which the coal is formed. Ash from inherent mineral matter is unimportant as far as the total quantity of ash is pertained. But Indian coals suffer from the major disadvantage, that the mineral matter content is not only high, but of intimately associated type, due to its drift origin. The several changes that occur, such as loss of water from silicate minerals, loss of carbon dioxide from carbonate minerals, oxidation of iron pyrite to iron oxide, and fixation of oxides of sulphur by bases such as calcium and magnesium. Because ash is quantitatively and qualitatively different from the mineral matter originally present in coal. In fact, combustion conditions determine the extent to which the weight change takes place and it is essential that standardized operations should be closely followed to ensure reproducibility.

Experimental Procedure

The empty crucible was cleaned by heating in a muffle furnace for one hour at 800^0C so that other mineral matter if presents get burnt. It was taken out, cooled to room

temperature and the weight is taken. Approximately 1gm of coal sample was weighed in the crucible and placed in a muffle furnace at 450^0C for 30 minutes and the temperature of the furnace was raised to 850^0C for 1hour. The crucible was taken out and placed in a desiccator and weighed.

$$\% \text{ Ash} = \frac{Z-X}{Y-X} \times 100$$

Where X = weight of empty crucible in grams

Y = weight of coal sample + crucible in grams (Before heating)

Z = weight of coal sample + crucible in grams (After heating)

Y - X = weight of coal sample, g

Z - X = weight of ash, g

Determination of Volatile Matter (VM)

The loss of mass in coal, corrected for moisture, which results when coal is heated in specified equipment's under prescribed conditions in Indian standard, is referred to as volatile matter of coal. Some of the elements of coal that converted to volatile matter are hydrogen, carbon monoxide, methane and other hydrocarbons, tar vapours, ammonia, some organic sulphur and oxygen containing deepens and some incombustible gases, such as carbon dioxide and water vapour, all of which come from the decomposition of organic materials in coal. And inorganic materials in coal contribute the water of hydration of mineral matter, carbon dioxide from carbonates and hydrogen chloride from inorganic chlorides to the volatile matter.

Experimental Procedure

For the determination of volatile matter a special volatile matter silica crucible (38mm height, 25mm external diameter and 22mm internal diameter) was used. The empty volatile matter crucible was weighed. Approximately 1g of coal sample (-212μ size) was weighed in the volatile matter crucible and it was placed inside a muffle furnace maintained at 925^oC with the lid covering the crucible. The heating was carried I the muffle furnace (Fig. 4.2) out exactly for seven minutes, after which the crucible was removed, cooled in air, then in a desiccator and weighed again. The calculation was done as per the following.

$$\% \text{ Volatile Matter} = \frac{Y-Z}{Y-X} \times 100 - M$$

Where X = weight of empty crucible, g

Y = weight of crucible + coal sample before heating, g

Z = weight of crucible + coal sample after heating, g

Y -X = weight of coal sample, g

Y- Z = weight of volatile matter + moisture, g

Determination of Fixed Carbon (FC)

The mathematical remaining after the determination of moisture, volatile matter and ash is fixed carbon by definition. Fixed carbon plus ash present the approximate yield of coke from coal. The value of fixed carbon is determined by subtracting from 100 the resultant summation of moisture (M), volatile matter (VM) and ash (A) with all portions on the same moisture reference basis.

$$\mathbf{FC = 100 - (M + VM + A)}$$

Where, moisture (M), volatile matter (VM), Ash (A) content of coal.

The results of proximate analysis is as presented in table 4.2

Table 4.2: Results of Proximate Analysis

Sl. No.	Sample	M (%)	A (%)	VM (%)	FC (%)
1.	BCCL-1	1.495	13.455	22.155	62.895
2.	BCCL-2	1.845	20.19	21.62	56.245
3.	BCCL-3	1.94	23.59	24.555	49.915
4.	BCCL-4	3.095	18.975	24.81	53.12
5.	CCL-1	1.945	28.685	20.425	48.945
6.	CCL-2	1.84	25.56	24.035	48.565
7.	CCL-3	2.24	43.13	22.135	32.494
8.	CCL-4	2.29	36.415	19.41	41.885
9.	JSPL-1	10.83	33.48	23.25	32.44
10.	JSPL-2	6.39	50.12	19.41	24.08
11.	JSPL-3	11.84	11.38	31.9	44.88
12.	NEC-1	6.05	2.29	41.72	49.94
13.	NEC-2	7.29	3.8505	26.943	61.916

14.	ECL-1	5.441	34.58	23.064	31.474
15.	SECL-1	4.852	16.9	21.846	56.402
16.	SECL-2	6.691	24.425	23.097	46.787
17.	SECL-3	4.947	8.986	23.605	62.48
18.	SECL-4	8.316	15.127	18.247	58.31
19.	SECL5	5.244	8.529	22.314	63.91

4.2.2 Determination of Calorific Value (IS 1350-1959)

The calorific value or heat of combustion or heating value of a sample of fuel/coal is defined as the amount of heat evolved when a unit weight (or volume in the case of a sample of gaseous fuels) of the fuel is completely burnt and the products of combustion cooled to a standard temperature of 298° K.

It is usually expressed in Gross Calorific Value (GCV) or Higher Heating Value (HHV) and Net Calorific Value (NCV) or Lower Calorific Value (LHV). Fuels should be compared based on the net calorific value. The calorific value of coal varies considerably depending on the ash, moisture content and the type of coal while calorific values of fuel oils are much more consistent.

Gross Calorific Value - Gross calorific value assumes all vapour produced during the combustion process is fully condensed. Number of heat units liberated when a unit mass of the fuel is burnt at constant volume in oxygen saturated with water vapour, the original material and final products being at approximately 25%. The calorific value Q, of coal is the heat liberated by its complete combustion with oxygen. Q is a complex function of the elemental composition of the coal. Gross Calorific value Q is mostly determined by experimental measurements. A close estimate can be made with the Delong formula:

$$Q = (144.4\ \%[C]) + (610.2\ \%\ [H])-(65.9\ \%\ [O]) + (0.39\ \%\ [O]\times 2)$$

Q is given in kcal/kg

Net Calorific Value - Net calorific value assumes the water leaves with the combustion products without fully being condensed. Number of heat units liberated when a unit mass of the fuel is burnt at constant volume in oxygen saturated with water vapour, the original and final materials being at approximately 25°C.

To convert gross calorific value to net calorific value, employ the formula:

$$NC = GC-53\ H$$

Where, NC = net calorific value in Kcal/kg,

GC = gross calorific value in Kcal/kg, and

H = percentage of hydrogen present in the coal sample, including hydrogen of moisture and of water of constitution.

Determination of Calorific Value of Coal by Bomb Calorimeter

Bomb calorimeter consists of a stout cylindrical chamber known as bomb (fig. given below) of stainless steel. This chamber is fitted with an air tight cover which can be screwed on the chamber. The cover has three terminals; two for sparking and one for the entry of oxygen. After forcing the oxygen into the chamber the passage can be blocked by screwing in the third terminal.

On the other side of the cover, there are two bent rods connected to two terminals. The bent rods have small holes through which two fuse wires are connected. There is the provision for putting the crucible containing the pellet tied to the fuse wire by means of a cotton thread. This whole set-up is placed in a bigger vessel containing a known quantity of water in it. The vessel is jacketed to minimize the heat loss by radiation. A stirrer is used for stirring the water in the bigger vessel. There is a provision for inserting the thermometer.

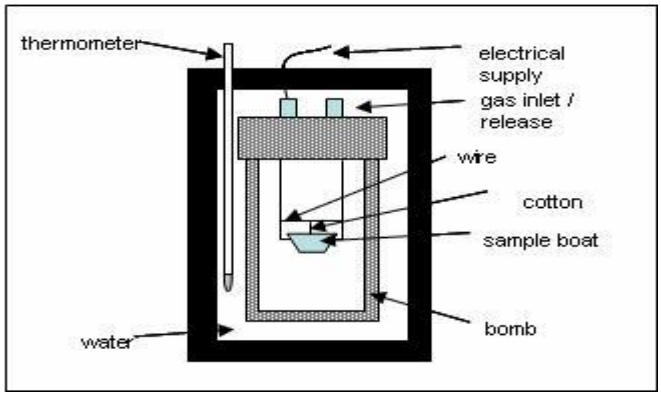

Fig 4.2 Schematic layout of Bomb Calorimeter

Fig.4.3 Structure of the Bomb Calorimeter used in project

Experimental Procedure:

- Approximately about 1gram of -212mm mesh size air dried coal sample is taken by weighing in a balance machine.
- A circular pellet is made with the coal and weighed again only the pallet and put inside the sample boat 04 cup holding sample.
- The calorimeter bomb is taken and about 10 cc of distilled water is poured into it.
- The pellet in the crucible is brought in contact with the fuse wire by means of a thread of cotton and the cover is then tightened.
- Oxygen is then admitted into the calorimeter at a pressure of about 25 atmospheres in such that there is no leakage of air.
- Litter of water is put into the Calorimeter vessel and the thermometer is inserted into the pocket.
- Necessary electrical connections are made and stirrer is adjusted in the corrected position. The stirring is done gently for five minutes for the highest reading taken digital indicator.
- The initial temperature reading is then taken.
- The bomb is now fired. Sparking and combustion of coal take place in the calorimeter.
- Temperature rises, noted the temperature at every 30 second interval for about 10-12 minutes after firing of the coal.

- Noted down the maximum temperature and calculation is done to find out calorific value according to the formula:

$$\text{Calorific Value (Kcal/Kg)} = \frac{\textbf{Water equivalent} * \textbf{Temp.Difference}}{\textbf{Sample weight}}$$

Temp. Difference = final reading – initial reading

Water equivalent = Specific heat capacity of water in Kcal/^{0}C (2366.5)

Sample weight = mass of the pellet

The calorific value of all the coal samples was determined by the following procedure and is presented in table 4.3.

Table 4.3: Results Calorific Value

Sl. No.	Sample name	Gross Calorific Value (KCal/kg)
1.	BCCL-1	7520.93
2.	BCCL-2	6995.31
3.	BCCL-3	6042.13
4.	BCCL-4	6173.48
5.	CCL-1	5705.39
6.	CCL-2	5813.49
7.	CCL-3	4638.13
8.	CCL-4	5094.55
9.	JSPL-1	3773.05
10.	JSPL-2	3665.07
11.	JSPL-3	5081.75
12.	NEC-1	6810.072
13.	NEC-2	4868.23
14.	ECL-1	3619.99
15.	SECL-1	4788.68
16.	SECL -2	4533.83
17.	SECL -3	5603.44
18.	SECL -4	5150.96
19.	SECL -5	4281.496

4.3 DETERMININATION OF SPONTANEOUS HEATING SUSCPETIBILITY OF COAL

4.3.1 Wet Oxidation Potential

The coal molecule may be considered as consisting of two parts such as one is condensed aromatic structure, which are resistant to oxidation and other one is the aliphatic or hydro aromatic structure that are more prone to oxidation and Presence of hydroxyl group in the aromatic structure part gives a very high degree of responsiveness to coal structure and they get oxidized faster. This is the cause for low rank coals are rather easily oxidized due to the above and also due to smaller degree of contraction of aromatic structures in them. Because low rank coals carry more branch aliphatic hydro-carbons. Since the high rank coals have structure close to that of graphite, it is less liable to oxidation and the products contain more aromatics than aliphatic. Lower rank coals on oxidation method large amounts of aliphatic acids compared to higher rank coals. When coal is contributed to alkaline permanganate, oxidation takes place and the concentration of manganite ion in solution increases relative to permanganate and there will be outcome change in the potential till all the oxidation possible in coal molecule is finish. Therefore, addition of coal to alkaline permanganate solution results in a change of potential of carbon electrode sank in the solution.

It is based on the chemical reaction of coal sample with solution of KMnO4 and KOH. The solution of alkaline potassium permanganate and potassium hydroxide with coal sample forms an electrochemical cell which on stirring produces EMF against a standard potential of 0.56V. The plot of the EMF‘s versus time gives an idea of the susceptibility of the coal sample towards spontaneous heating. (Tarafdar and Guha, 1989; Sahu et al., 2004)

Fig. 4.4 Wet oxidation potential set up used in project

Experimental Procedure:

The beaker along with the electrodes (Figs. 4.6) was placed over a magnetic stirrer such that a homogeneous mixture of coal and alkali solution is maintained. The Teflon coated fish of the magnetic stirrer was placed inside the beaker. 0.5 g of coal sample of –212 (μ) size was mixed with 100 ml of deci-normal solution of potassium permanganate ($KMnO_4$) in 1N potassium hydroxide (KOH) solution in a beaker and the coal sample was subjected to wet oxidation process. The coal-oxidant suspension was continuously stirred using the magnetic stirrer. The potential difference (EMF) was recorded between the calomel and carbon electrodes over a period of time by using a millivolt meter till the potential difference attained a nearly constant value. The graphs between Times vs. EMF (millivolt) for all the samples are plotted in Figs. (4.4 to 4.9). Different samples require different time duration for attaining a nearly constant potential difference (ΔE). It was observed that almost all the coal samples attained a constant value after 30 minutes. Therefore this time period was chosen to find out the wet oxidation potential difference for a comparative study. The results are presented in Table 4.4.

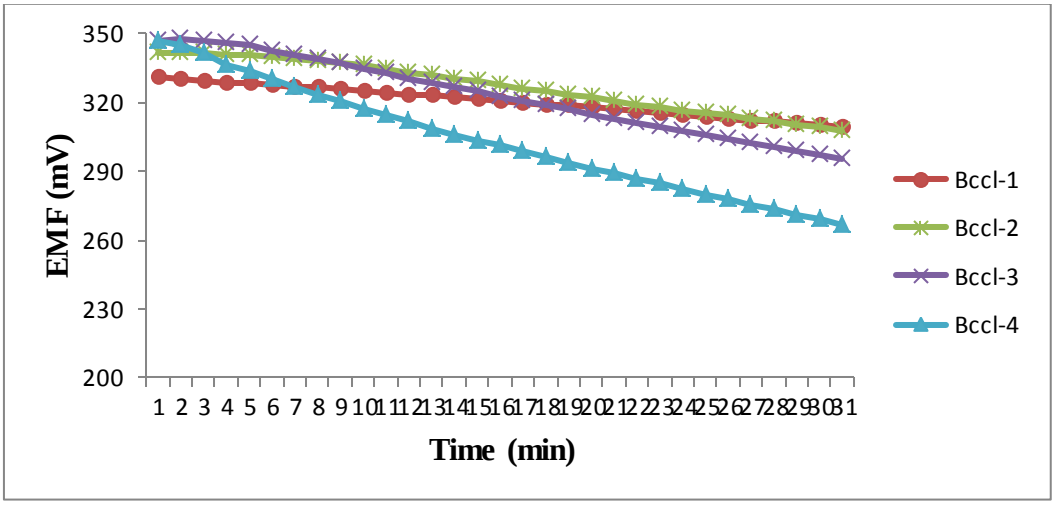

Fig. 4.5 Wet oxidation potential curve for BCCL samples

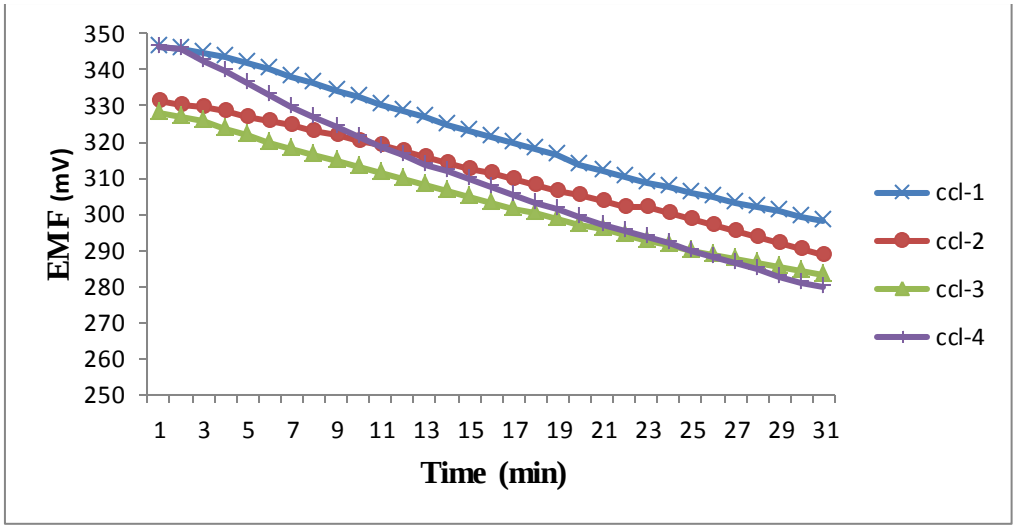

Fig. 4.6 Wet oxidation potential curve for CCL samples

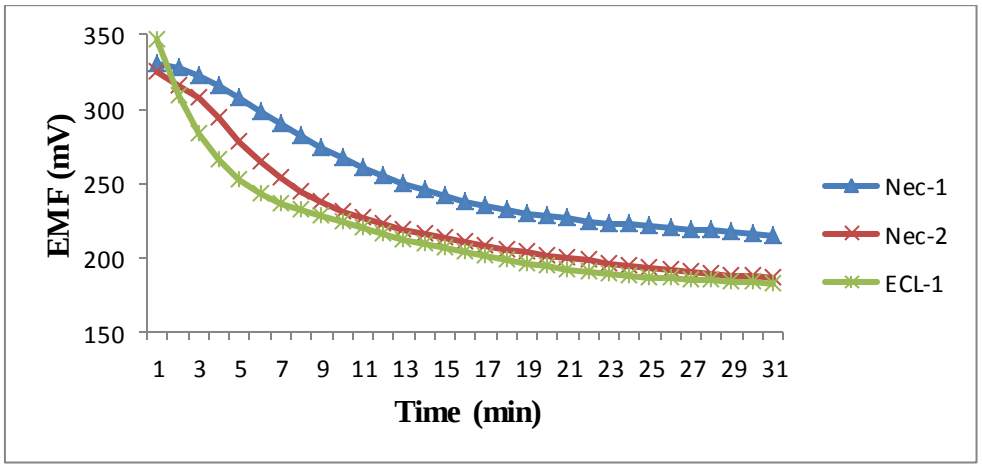

Fig. 4.7 Wet oxidation potential curve for ECL and NEC samples

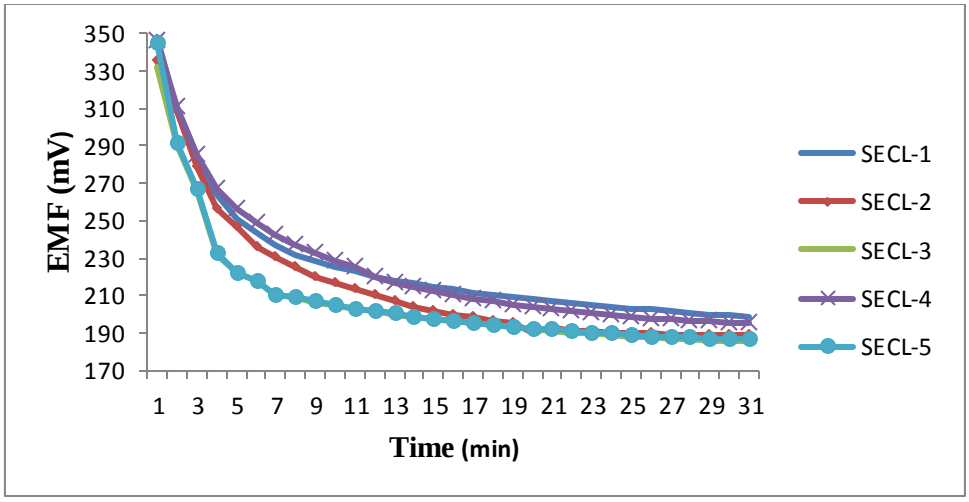

Fig. 4.8 Wet oxidation potential curve for SECL samples

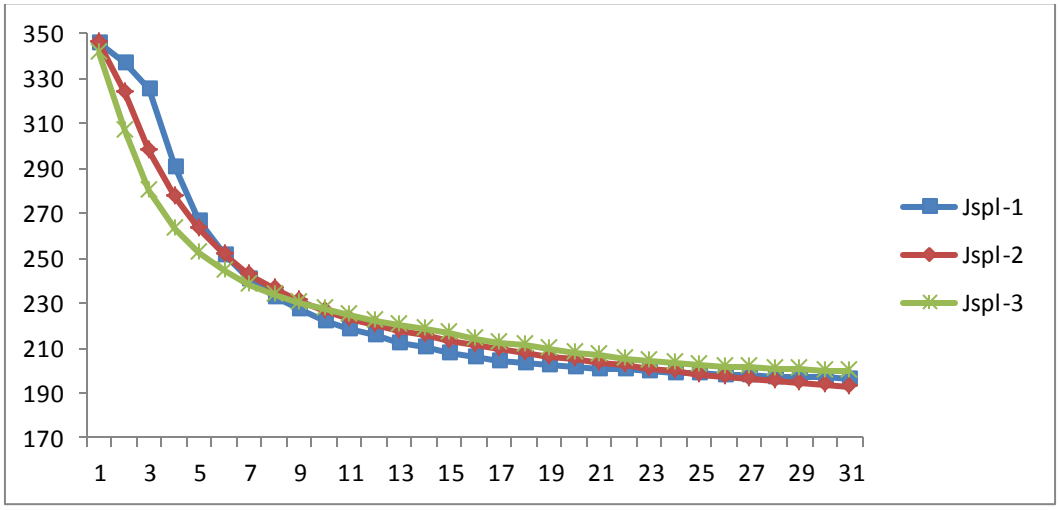

Fig. 4.9 Wet oxidation potential curve for JSPL samples

Table 4.4 Results of Wet Oxidation Potential Analysis

Sl. No.	Sample name	WOPD after 30 minutes (mV)
1.	BCCL-1	21.5
2.	BCCL-2	33.7
3.	BCCL-3	50.8
4.	BCCL-4	79.5
5.	CCL-1	47
6.	CCL-2	42.5
7.	CCL-3	44.6
8.	CCL-4	66.5
9.	JSPL-1	149.2

10.	JSPL-2	153.2
11.	JSPL-3	142
12.	NEC-1	114.8
13.	NEC-2	138
14.	ECL-1	162.9
15.	SECL-1	149
16.	SECL -2	146.7
17.	SECL -3	147.3
18.	SECL -4	150.5
19.	SECL -5	158.3

4.3.2 Differential Thermal Analysis

Differential thermal analysis involves heating a small test specimen at a constant rate and continuously recording the instantaneous temperature difference (ΔT) between it and as identically heated inert reference material as a function of sample temperature (T). The resultant thermogram, a record of ΔT against T, with its characteristics heat changes and intensities, depicts the physical or chemical changes of the material at that particular temperature and is characteristic of that material used.

Experimental Procedure

Differential thermal analysis was carried out by a Differential Thermal Analyser machine. The standardised parameters proposed by Banerjee and Chakravorty (1967) were followed while performing the experiments. The DTA apparatus consists of a sample and reference holder, a furnace, a temperature programmer to maintain constant temperature rate and an output to monitor the test (Fig. 4.10). The sample holder has two thermocouples each for reference and sample. The sample is contained in a small crucible. The thermocouple should not be in direct contact with sample. By the temperature programmer the temperature is made to rise at a constant rate and the temperature difference of the sample and reference is plotted against time.

DTA thermograms were obtained until 450^0C at a heating rate of 5^0C per min which is automatically plotted by the software in computer. It has been shown by Banerjee and Chakravorty (1967) that a thermo gram of coal can be divided into three segments or stages (Fig. 4.11). These stages have also been identified in the thermo grams generated

from the results of the experiments as indicated in Figures (4.12 to 4.30). In the initial stage of heating (stage I), the endothermic reaction predominates, probably due to the release of inherent moisture in coal. In the second stage (stage II), the exothermic reaction becomes significant, but the rate of heat release is not steady all through, as it changes with temperature. A steep rise in heat evolution is observed in the third stage (stage III). The rate of temperature rise in stage II is mentioned by different researchers, viz. Banerjee and Chakravorty (1967), Gouws and Wade (1989); as being less for coals with less susceptibility to spontaneous heating. The exothermicity in stage III is not regarded as a reliable indicator of the self-heating risk, because it may be equally high for low rank coals. However, the temperature of transition or characteristic temperature or onset temperature is considered to be significant. It is considered that in lower temperatures, the coal is more susceptible towards spontaneous heating. Therefore, all the thermo grams were analysed for the following details.

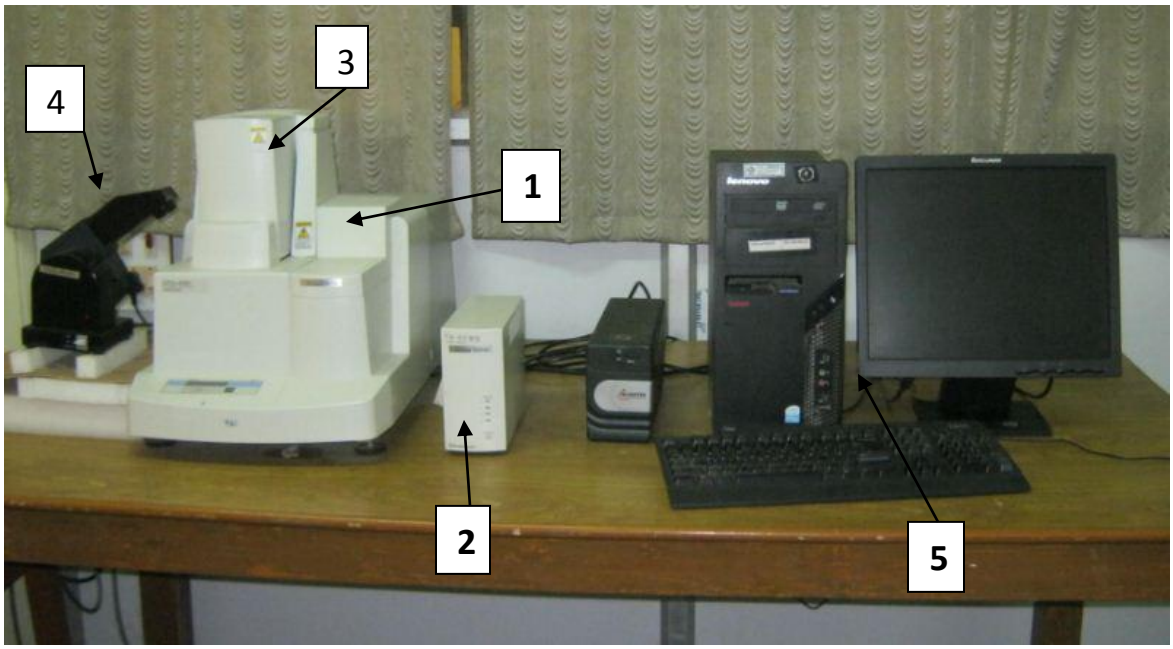

FIG.4.10 Differential thermal analysis set up used in project

1) Differential Thermal Analyser (DTA- 60H) 4) Blower

2) TA – 60 WS Collection Monitor 5) Computer for Data Processing

3) Tubular Furnace

Onset temperature or characteristic temperature

The onset temperature or characteristic temperature (Tc) was determined by the following procedure:

- A tangent was drawn at the inflexion point of the endothermic region and another tangent was drawn at the rising portion of the curve of stage III in the computer.
- The intersection between the two tangents gives the characteristic temperature or transition temperature.

The characteristic temperature of all the thermograms was obtained by following the software available with the equipment.

Slopes of stage II of the thermo gram

In the thermo grams obtained from the experiments, linear stage II exothermicity was not observed. In view of the disjointed nature of stage II slopes it was further divided into two different regions, viz. stage IIA and stage IIB. The following three parameters of stage II were determined for further analysis.

- Average slope of stage IIA.
- Average slope of stage IIB.
- Overall slope of stage II.

The slopes of all the thermograms were obtained by using Microsoft Excel software.

The results of characteristic temperature and the slope values obtained by following the above procedure have been presented in Table 4.5.

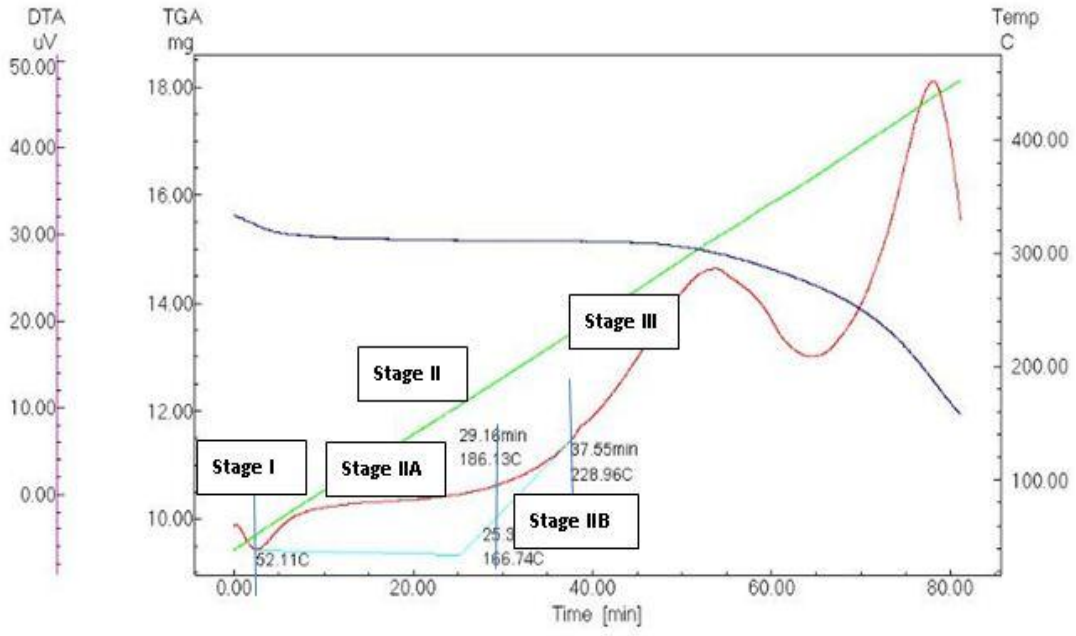

Fig. 4.11 Different stages and characteristics temperature presented on the thermogram of DTA (Panigrahi et.al. 2004)

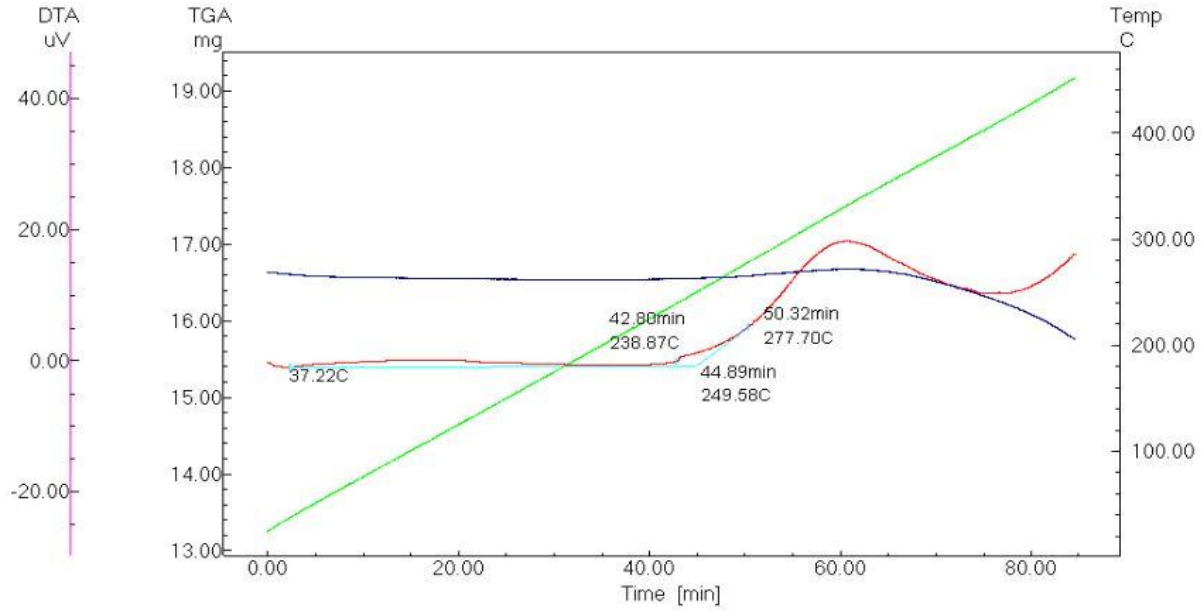

Fig. 4.12 DTA Thermogram for Sample BCCL 1

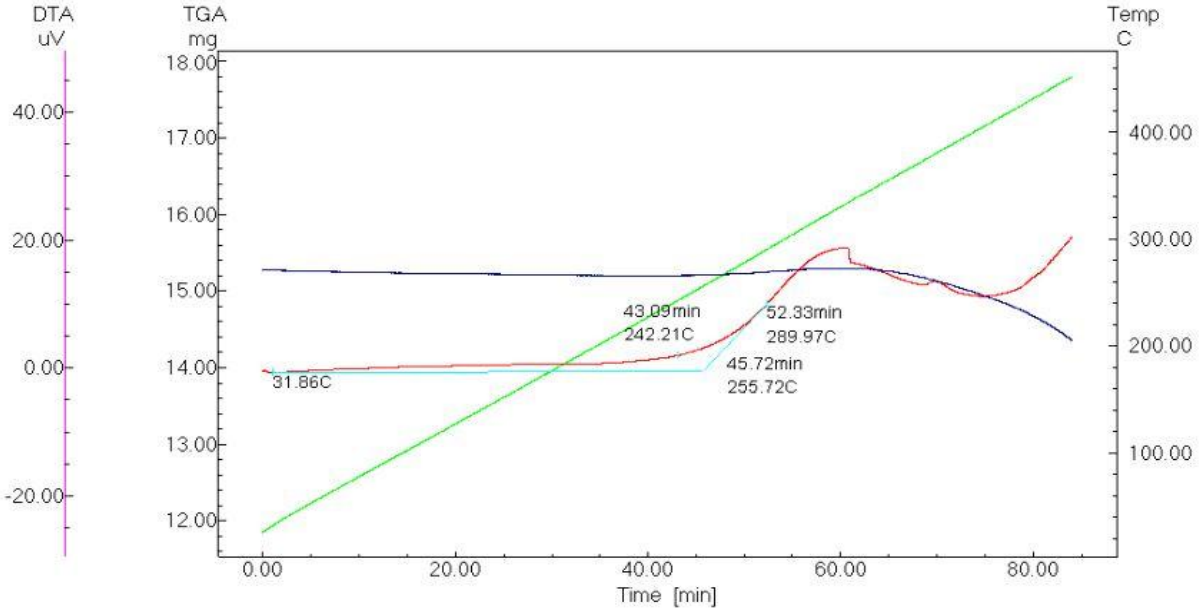

Fig. 4.13 DTA Thermogram for Sample BCCL 2

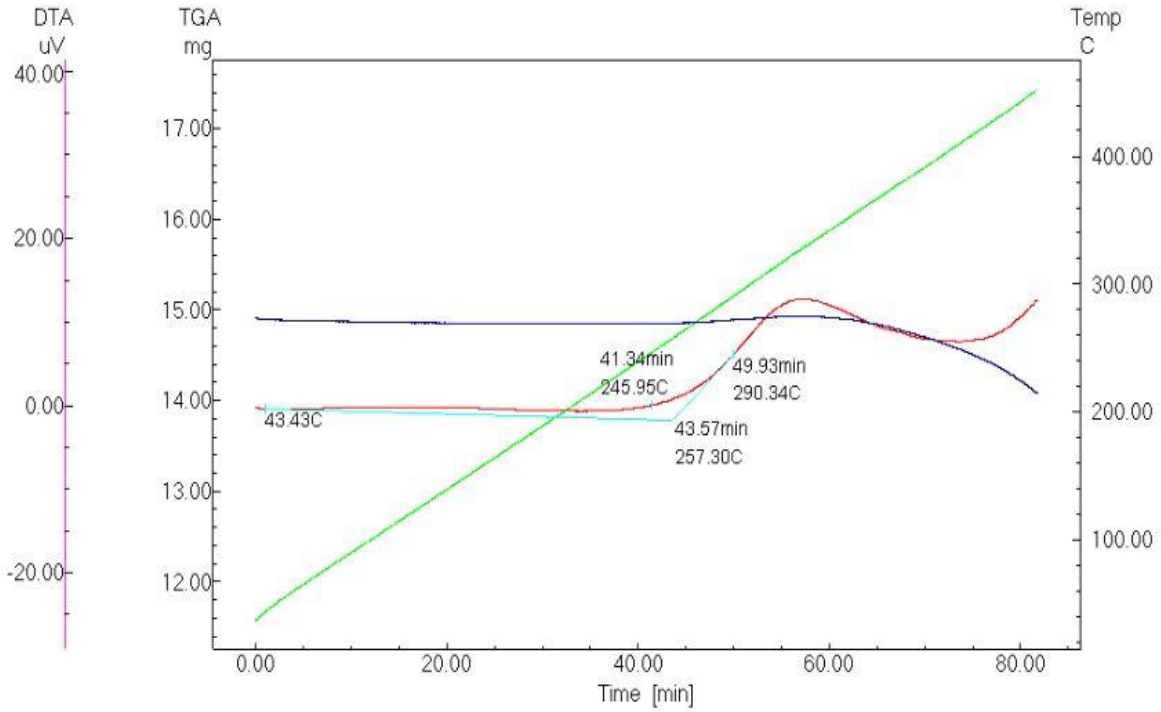

Fig. 4.14 DTA Thermogram for Sample BCCL 3

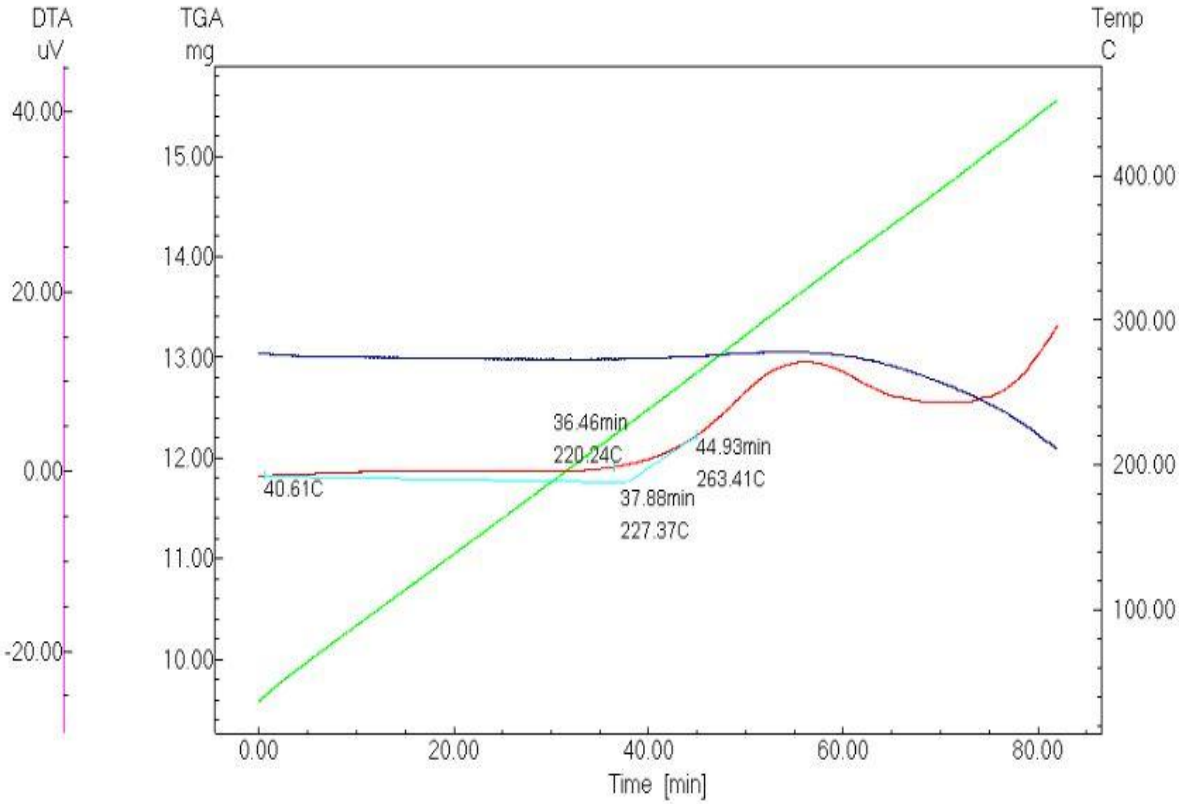

Fig. 4.15 DTA Thermogram for Sample BCCL 4

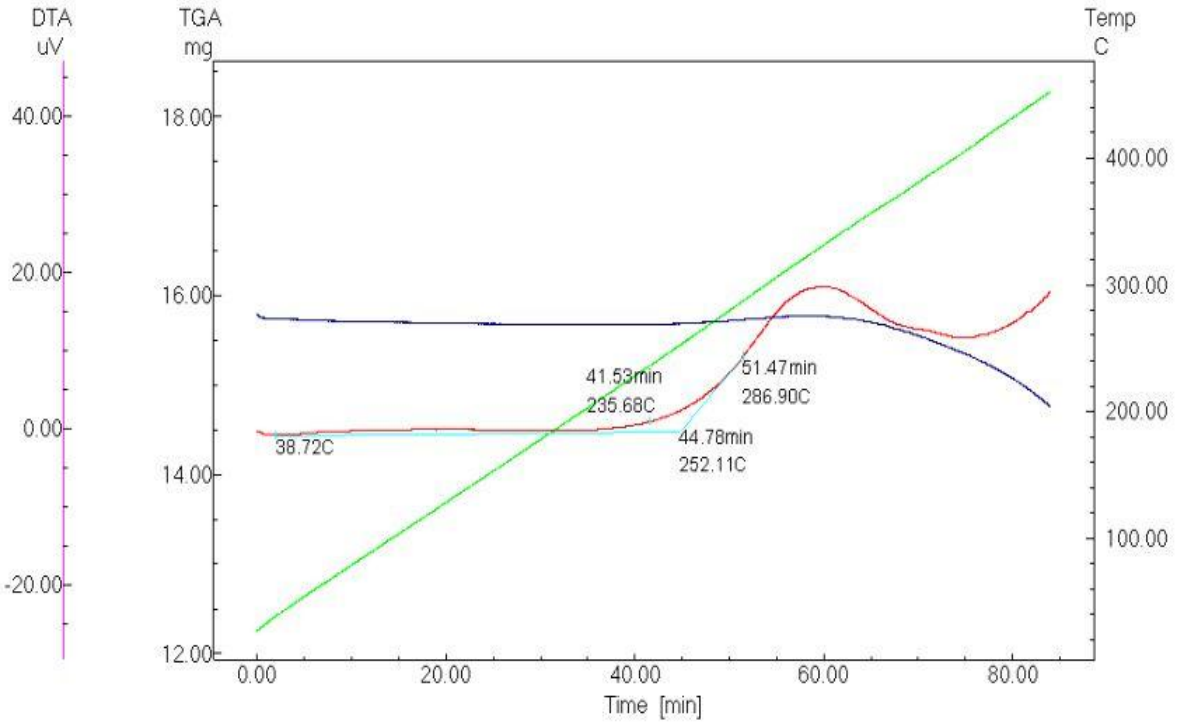

Fig. 4.16 DTA Thermogram for Sample CCL 1

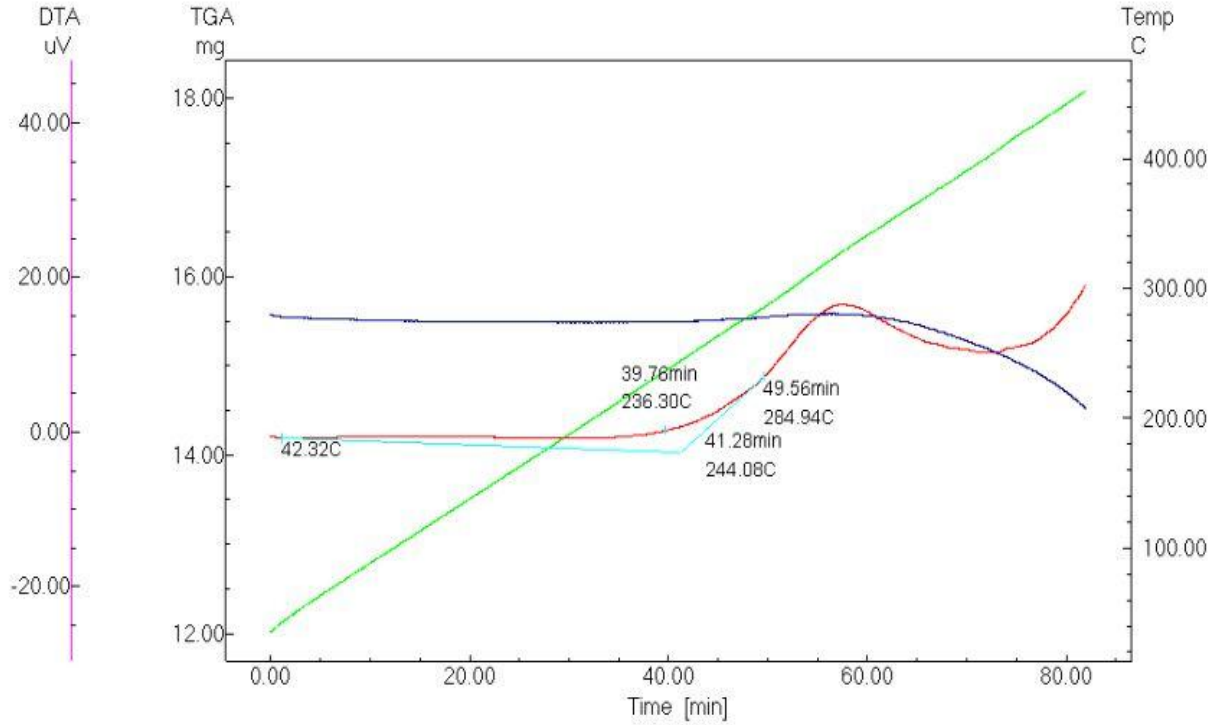

Fig. 4.17 DTA Thermogram for Sample CCL 2

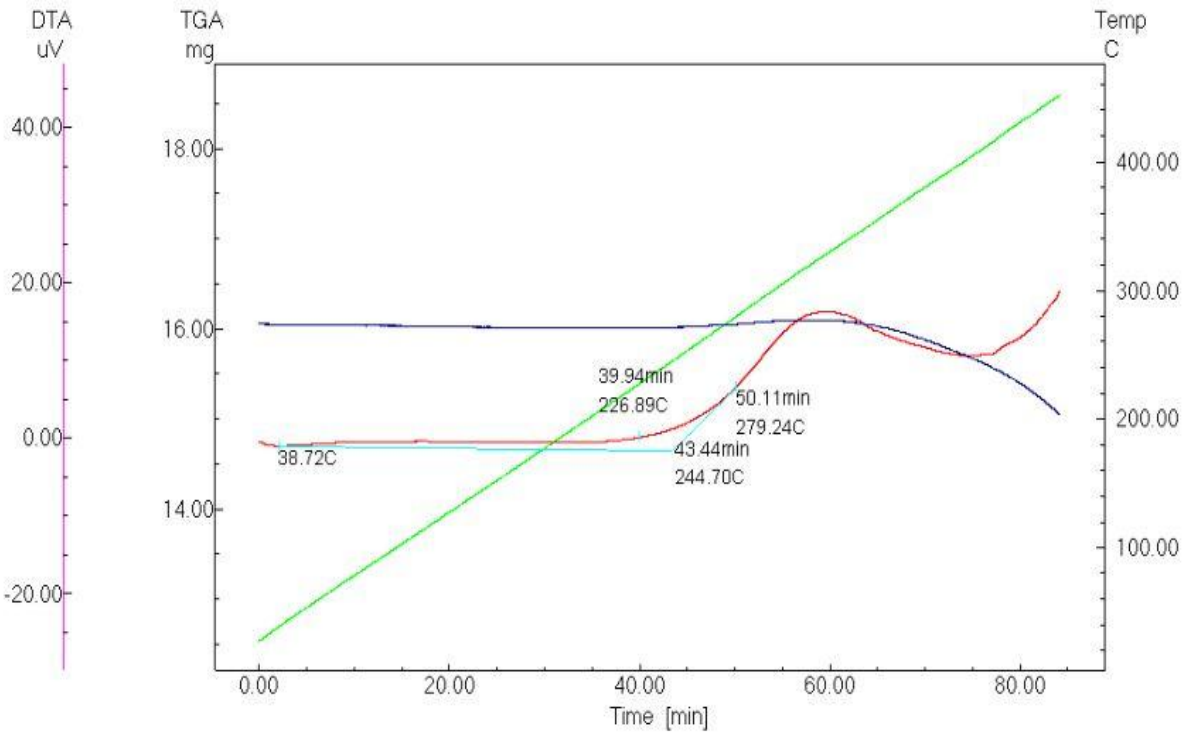

Fig. 4.18 DTA Thermogram for Sample CCL 3

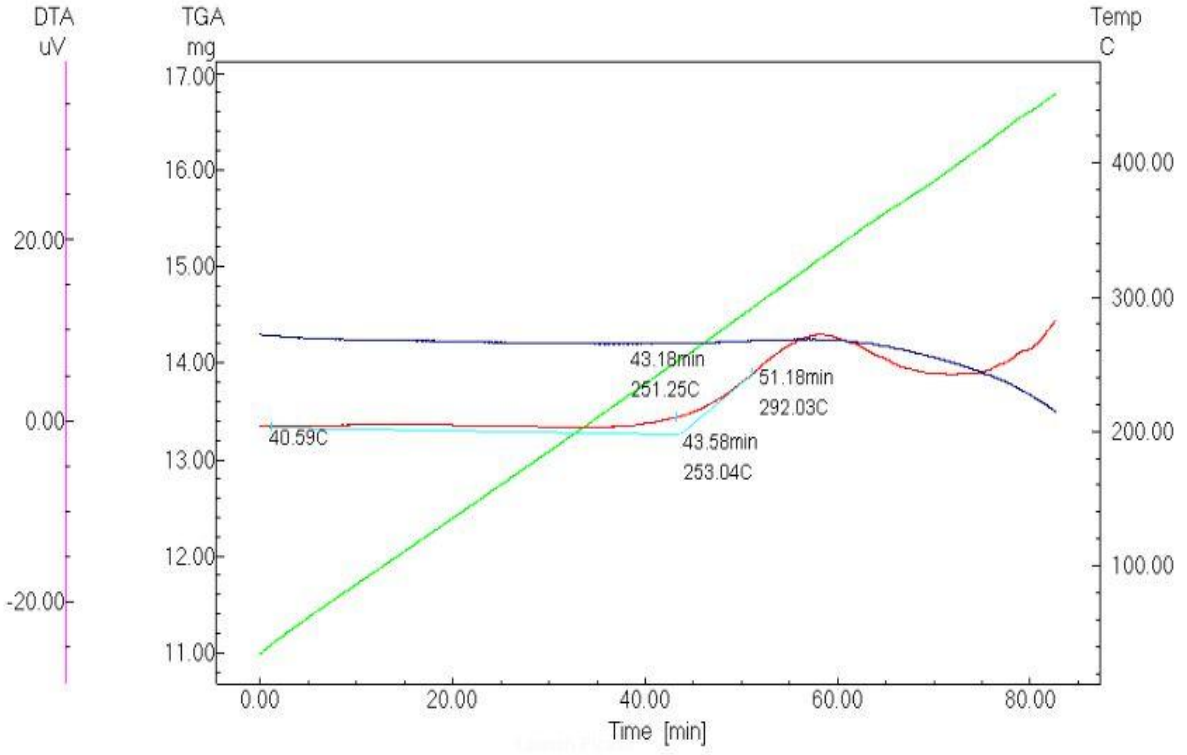

Fig. 4.19 DTA Thermogram for Sample CCL 4

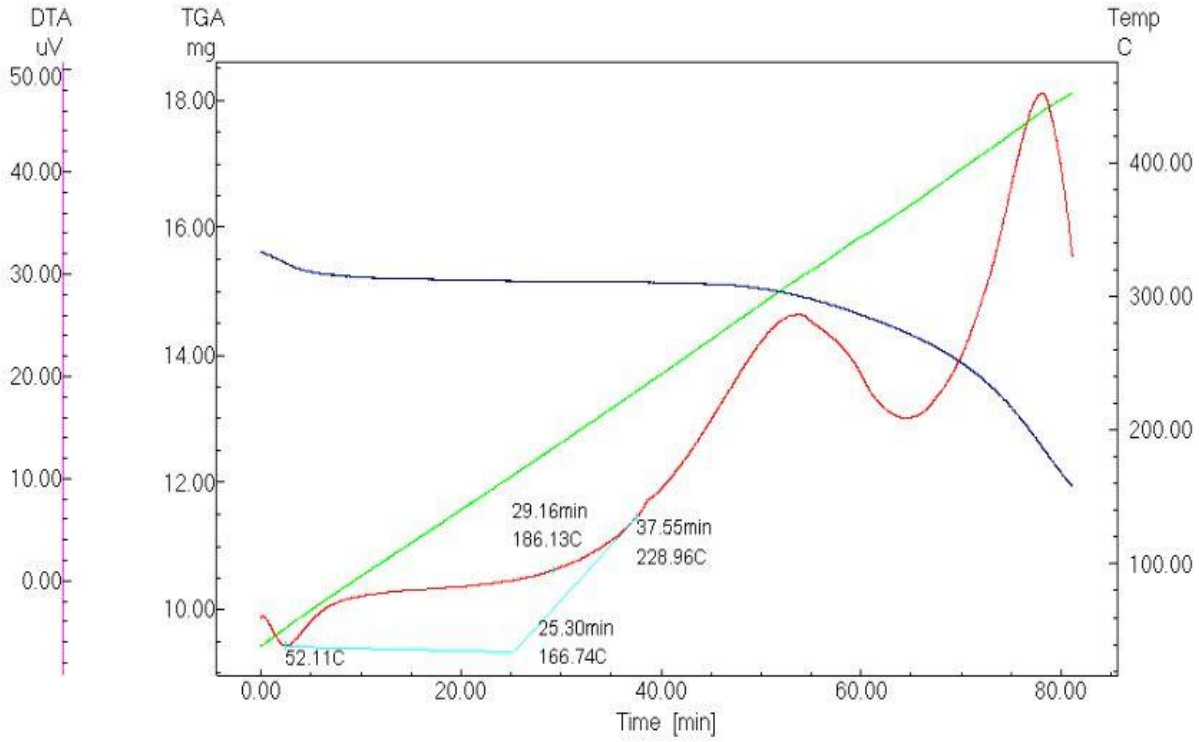

Fig. 4.20 DTA Thermogram for Sample JSPL 1

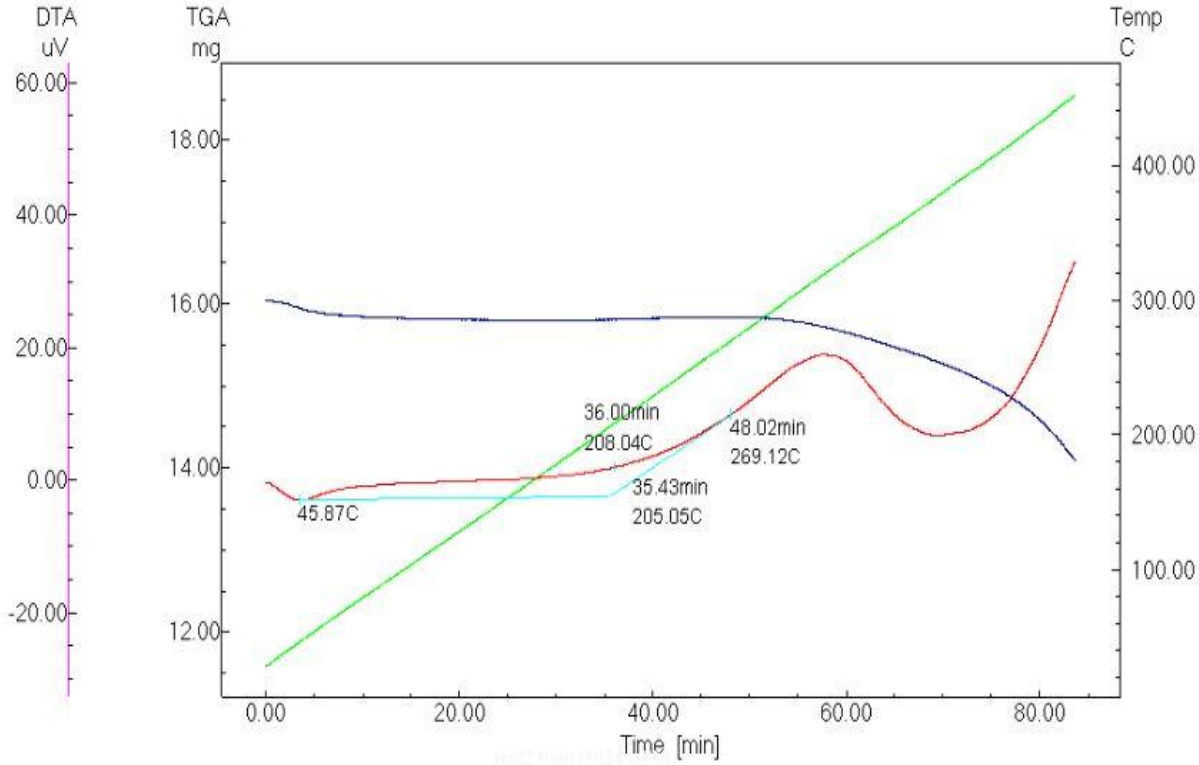

Fig. 4.21 DTA Thermogram for Sample JSPL 2

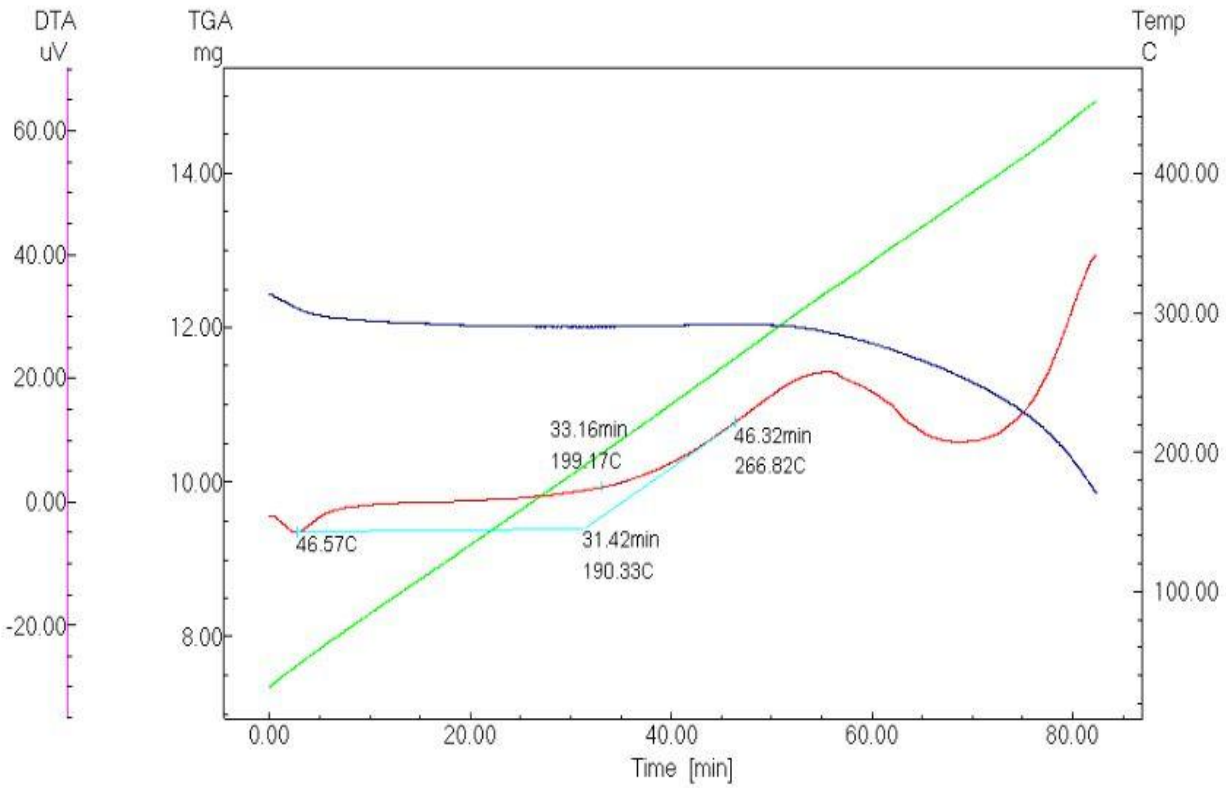

Fig. 4.22 DTA Thermogram for Sample JSPL 3

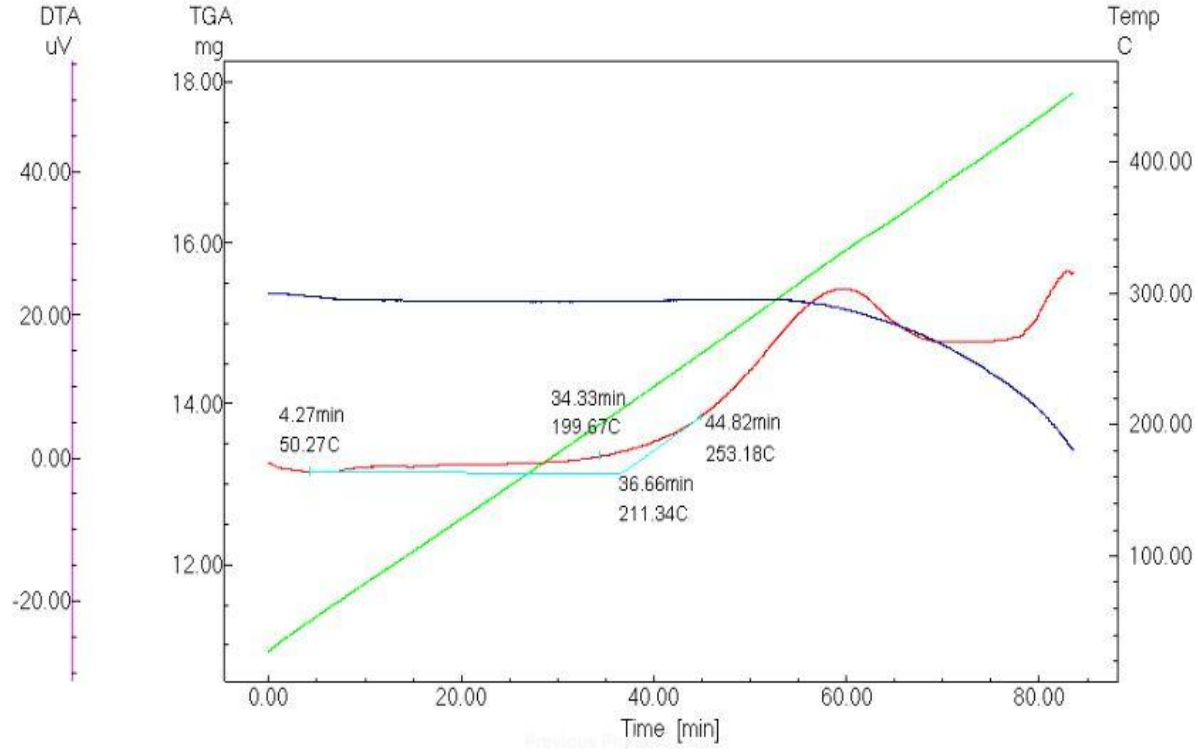

Fig. 4.23 DTA Thermogram for Sample NEC 1

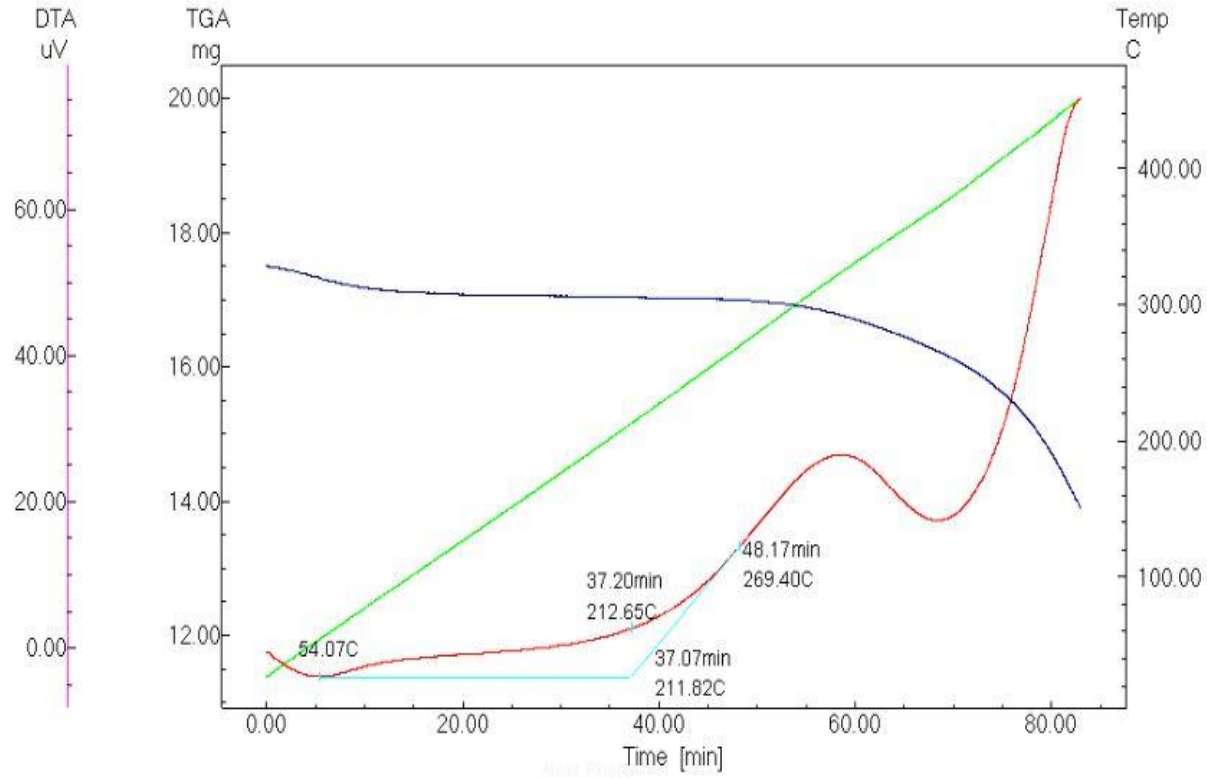

Fig. 4.24 DTA Thermogram for Sample NEC 2

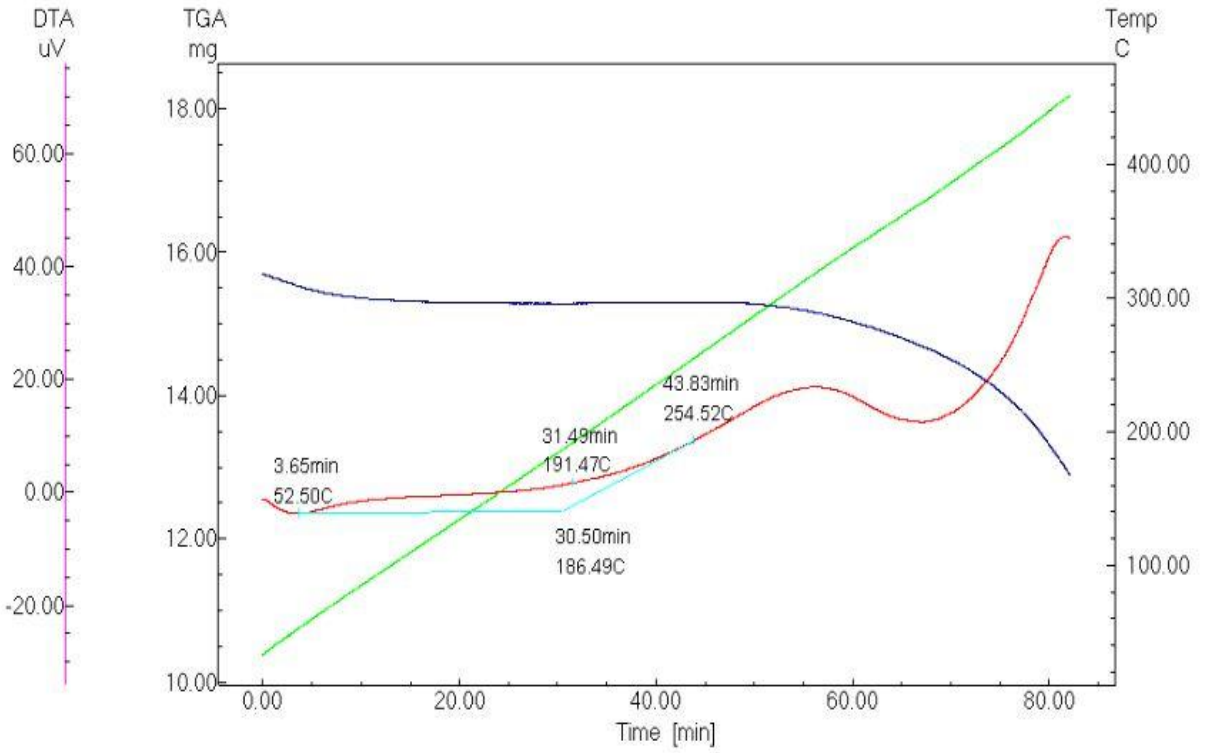

Fig. 4.25 DTA Thermogram for Sample ECL 1

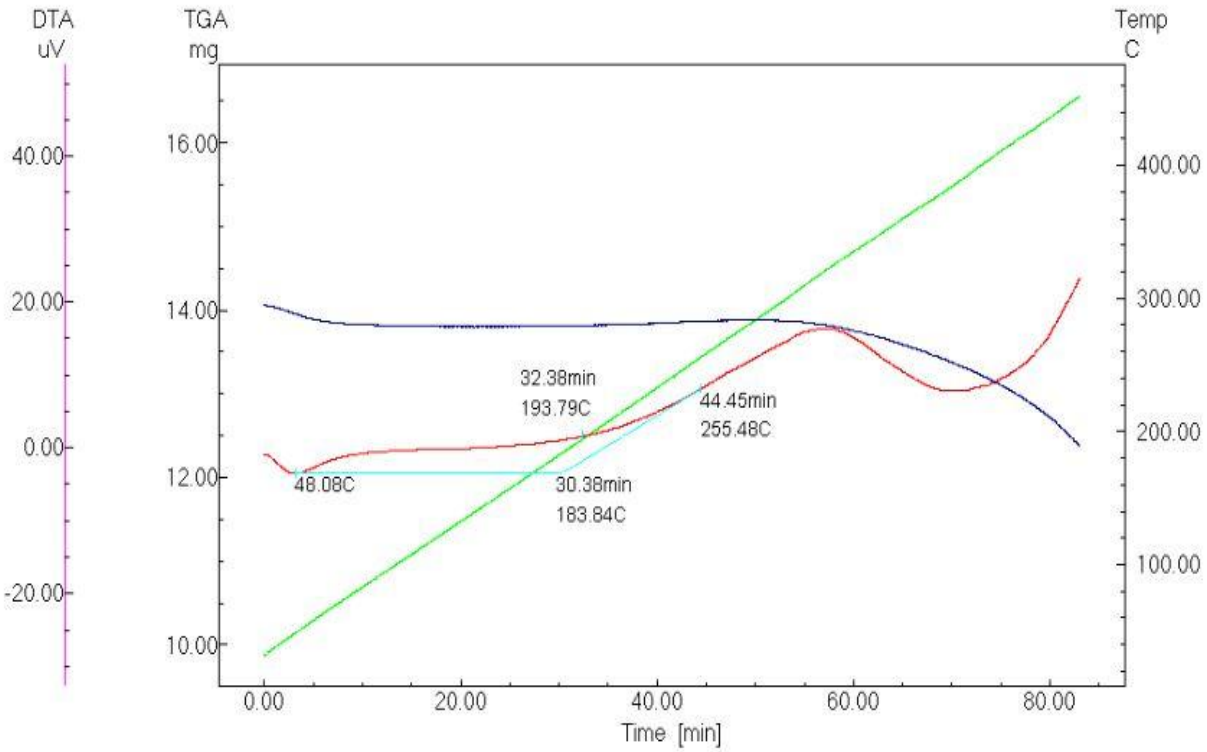

Fig. 4.26 DTA Thermogram for Sample SECL 1

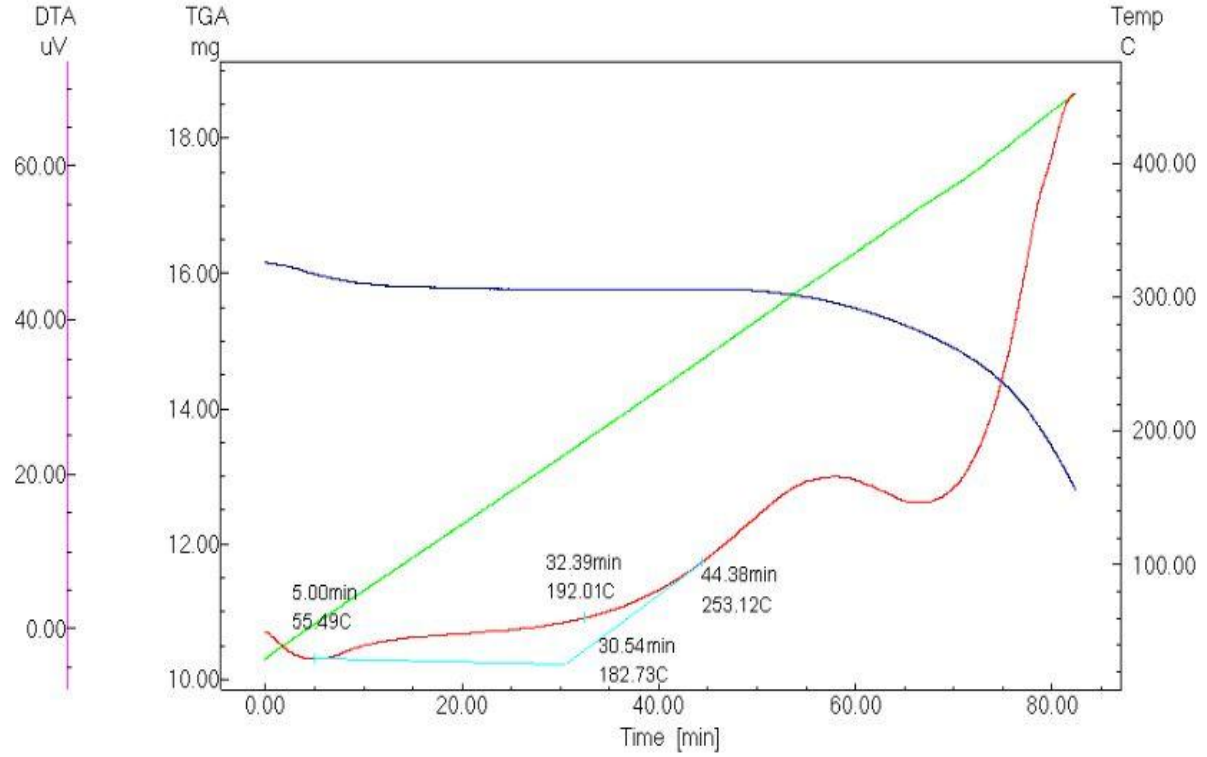

Fig. 4.27 DTA Thermogram for Sample SECL 2

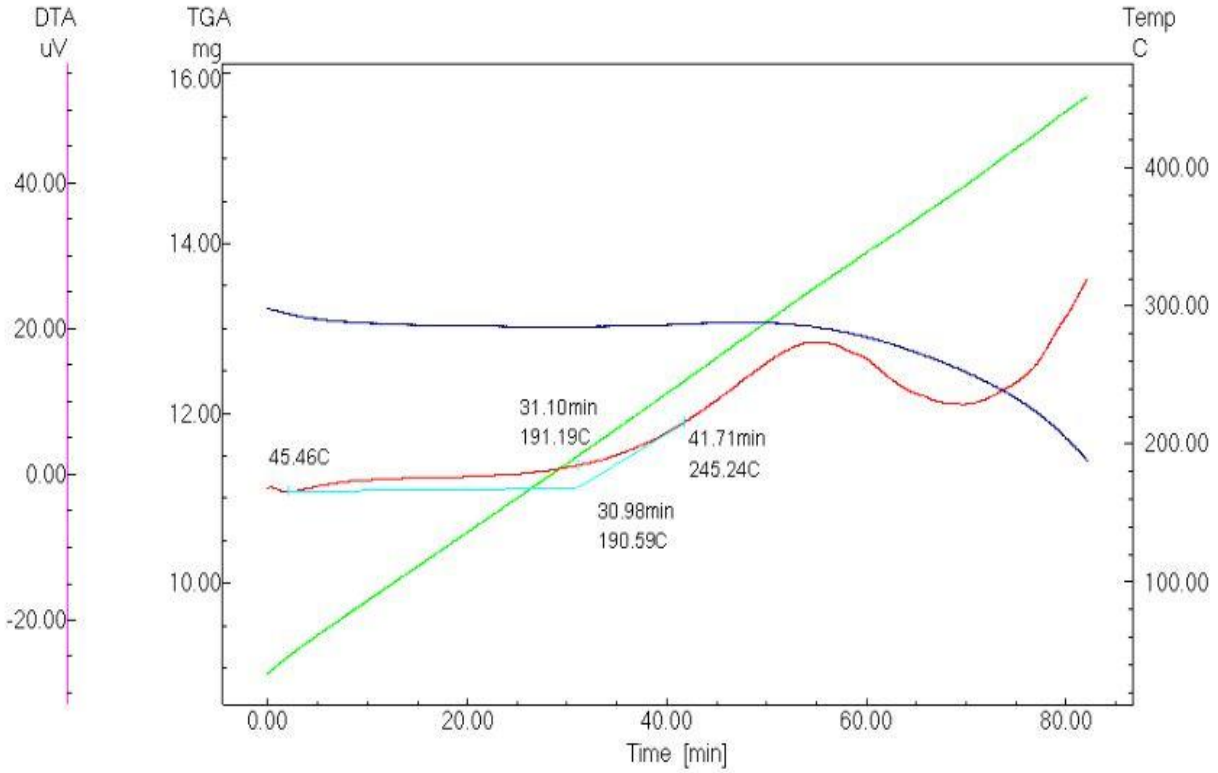

Fig. 4.28 DTA Thermogram for Sample SECL 3

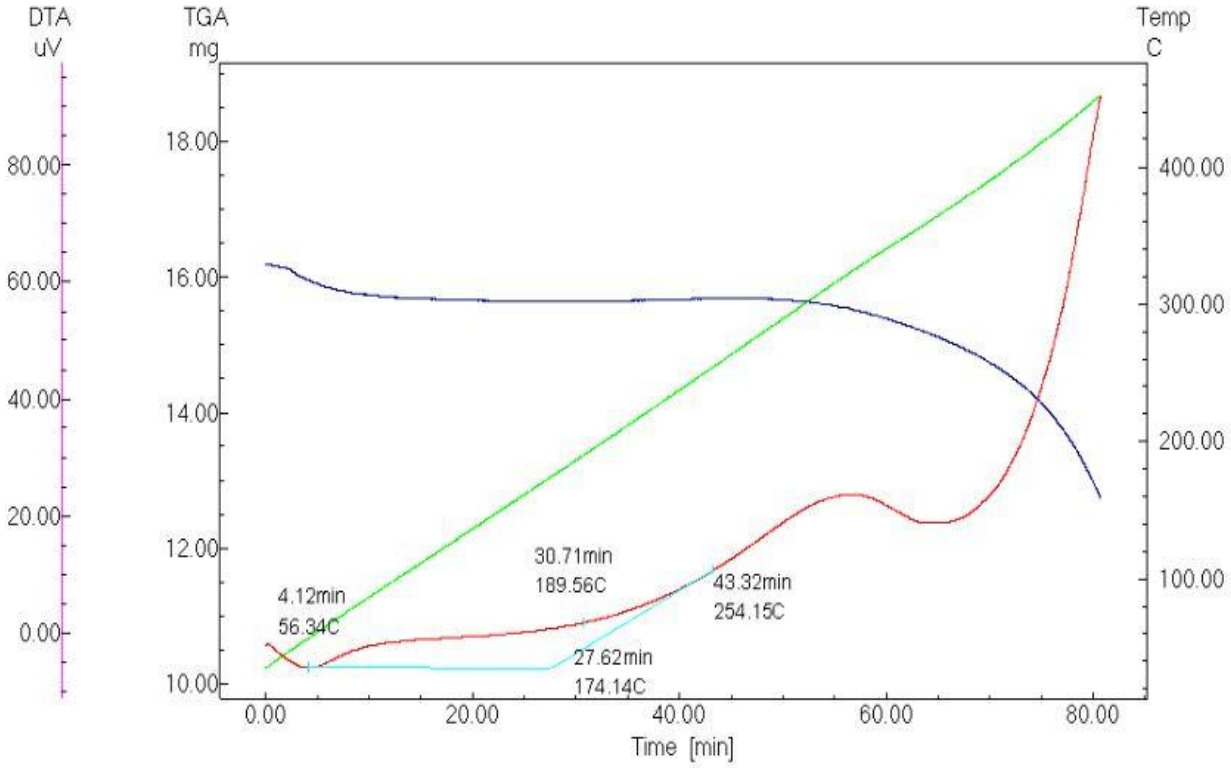

Fig. 4.29 DTA Thermogram for Sample SECL 4

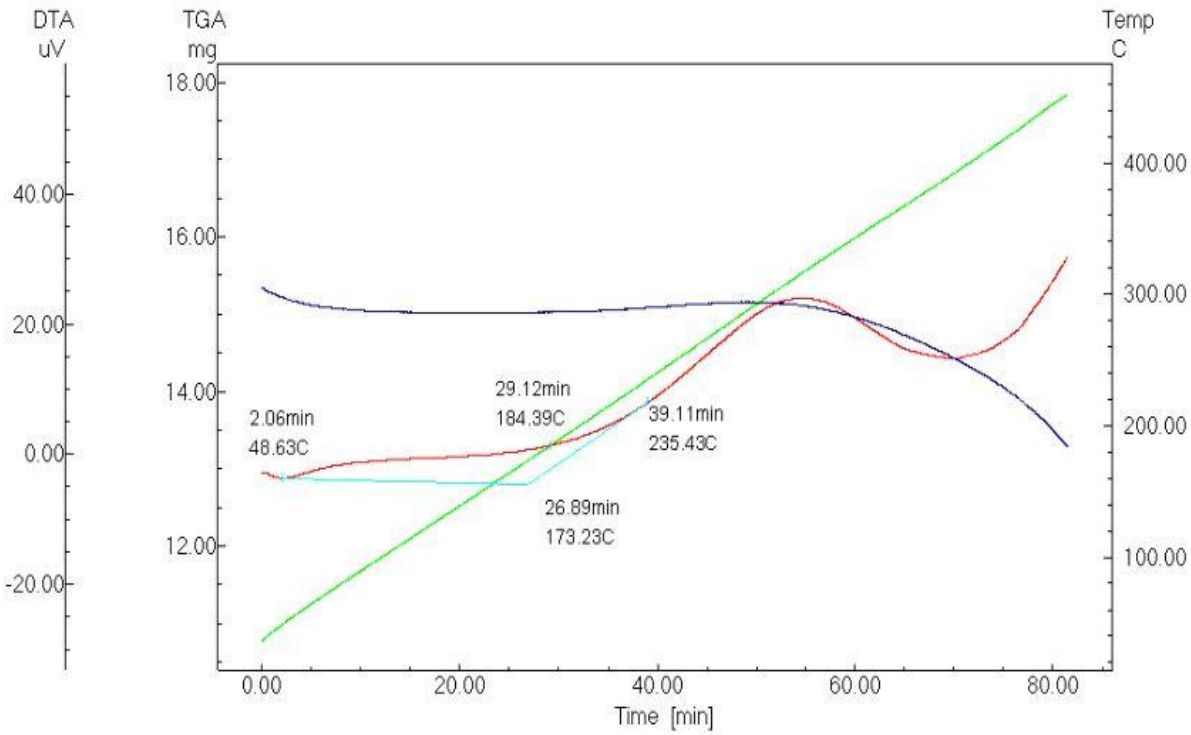

Fig. 4.30 DTA Thermogram for Sample SECL 5

Table 4.5: Results of DTA

Sl. No.	Sample	Tc (^{0}C)	Slopes of		
			IIA	Stage IIB	Stage II
1.	BCCL-1	249.58	-0.001	0.104	0.006
2.	BCCL-2	255.72	0.007	0.140	0.018
3.	BCCL-3	257.30	-0.001	0.114	0.007
4.	BCCL-4	227.37	0.002	0.067	0.008
5.	CCL-1	252.11	0.003	0.136	0.016
6.	CCL-2	244.08	0.0008	0.116	0.013
7.	CCL-3	244.70	0.001	0.102	0.012
8.	CCL-4	253.04	0.0003	0.102	0.008
9.	JSPL-1	166.74	0.031	0.099	0.037
10.	JSPL-2	205.05	0.017	0.109	0.033
11.	JSPL-3	190.33	0.024	0.132	0.044
12.	NEC-1	211.34	0.008	0.083	0.021
13.	NEC-2	211.82	0.027	0.168	0.049
14.	ECL-1	186.49	0.025	0.100	0.040
15.	SECL-1	183.84	0.020	0.090	0.032

16.	SECL -2	182.73	0.027	0.099	0.040
17.	SECL -3	190.59	0.015	0.091	0.028
18.	SECL -4	174.14	0.038	0.118	0.053
19.	SECL -5	173.23	0.024	0.111	0.037

Chapter-05

DISCUSSION AND CONLUSIONS

Chapter-05

5. DISCUSSION AND CONCLUSION

5.1 DISCUSSION

In order to evaluate the role of intrinsic factors in the spontaneous heating of coal, 19 coal samples were collected from different mines of our country. Out of the 19 coal samples, 4 WERE from Bharat Coking Coalfields Limited (BCCL), 4 from Central Coalfields Limited (CCL), 3 from Jindal Steel and Power Ltd. (JSPL), 1 from Eastern coal fields Limited, 2 from North Easterner Coalfields and 5 from South Eastern Coalfields Ltd. (SECL). The intrinsic properties were measured by proximate analysis and calorific value and the spontaneous heating susceptibility of the coal samples were determined by wet oxidation potential analysis and differential thermal analysis. Correlation studies have been carried out between the intrinsic properties and the susceptibility indices for finding their interrelationship. The following points may be noted from the analysis:

- The moisture content of coal varied from 1.495 % to 11.84 %. The volatile matter of all coals varied from 18.247 % to 41.72 % and the ash content varied from 2.29 % (NEC-1 coal) to 50.12 % (JSPL-2 coal). The fixed carbon content of the coal samples varied from 24.03 to 63.91.
- Calorific value of these coals is changes from 3773.05 to 7520.93 KCal/kg.

- Higher the difference of wet oxidation potential difference more is the susceptibility to spontaneous combustion. The wet oxidation potential value of BCCL and CCL coals are very low, so these coals are less susceptible to spontaneous heating. The wet oxidation potential difference values of the coal samples from SECL were found to be very high (from 149.0 to 158.3 mV). Therefore these are very highly susceptible to spontaneous heating.

- The characteristic temperature (Tc) obtained from DTA thermograms from SECL-5 sample is the lowest (173.23^0C) which indicates that it is the most susceptible to spontaneous heating. This is also corroborated from the wet oxidation potential difference value (158.3mV)) which is the second highest among all the samples.

- The characteristic temperature (Tc) for sample number BCCL-3 is the highest (257.30^0C) indicating that it is the lowest susceptible. The wet oxidation potential of this sample is also fairly low (50.8mV). It has also been seen in actual field condition that it takes a very long time for the coal to catch fire after being exposed.

Correlation studies were carried out between the different susceptibility indices and the coal characteristics as obtained from proximate analysis. The susceptibility indices were taken as dependent variables and each constituent obtained from the proximate analysis and GCV as an independent variable. The correlation coefficients obtained in all cases are presented in Table 5.1.

Table 5.1 Results (Correlation Coefficient, r) of correlation analysis

Variables	M	A	VM
EMF	0.94	0.36	0.13
Tc	0.91	0.26	0.08
IIA	0.62	0.24	0.31
IIB	0.43	0.21	0.23
II	0.41	0.19	0.33

It may be observed that the moisture content of the coal samples had a very good correlation with wet oxidation potential difference (correlation coefficient = 0.94), Characteristic temperature obtained from DTA thermogram (correlation coefficient = 0.91) and stage IIA slope of DTA thermogram (correlation coefficient = 0.62). The plot of EMF vs moisture, Tc vs Moisture and slope of stage IIA vs Moisture has been presented in Figures 5.1 to 5.3 respectively. It is generally believed that with increase in moisture content there is increase in spontaneous heating susceptibility of coals.

The correlation coefficients in all other case were found to be very low.

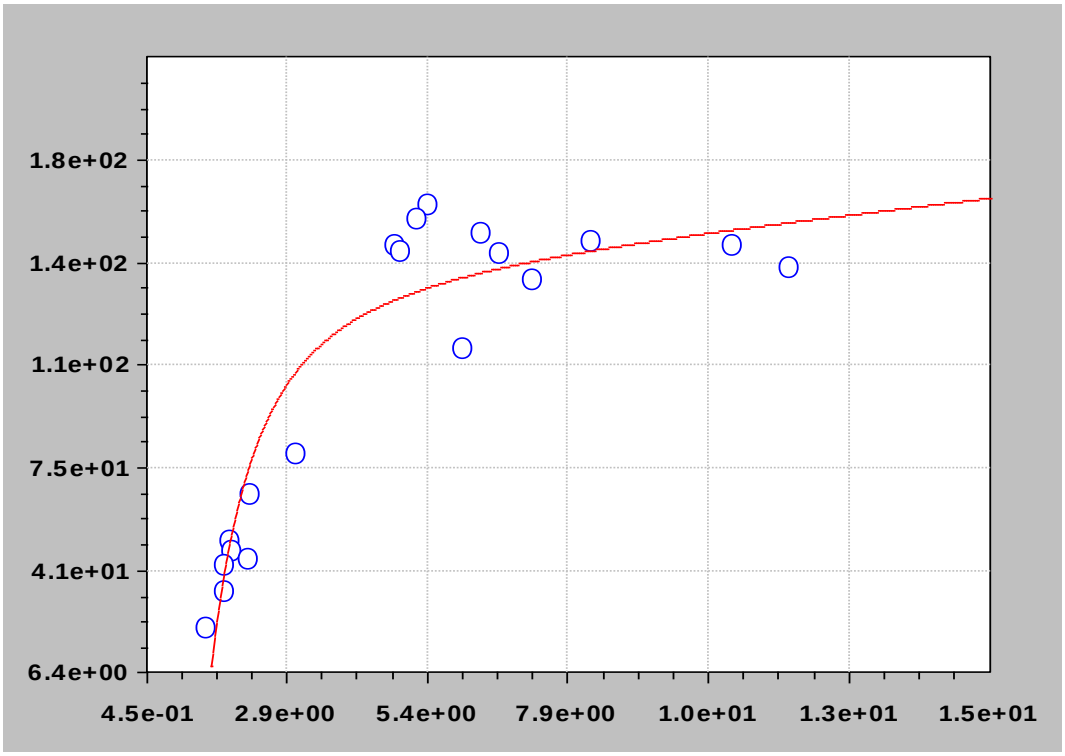

Figure 5.1: Plot of EMF Vs Moisture of the coal samples.

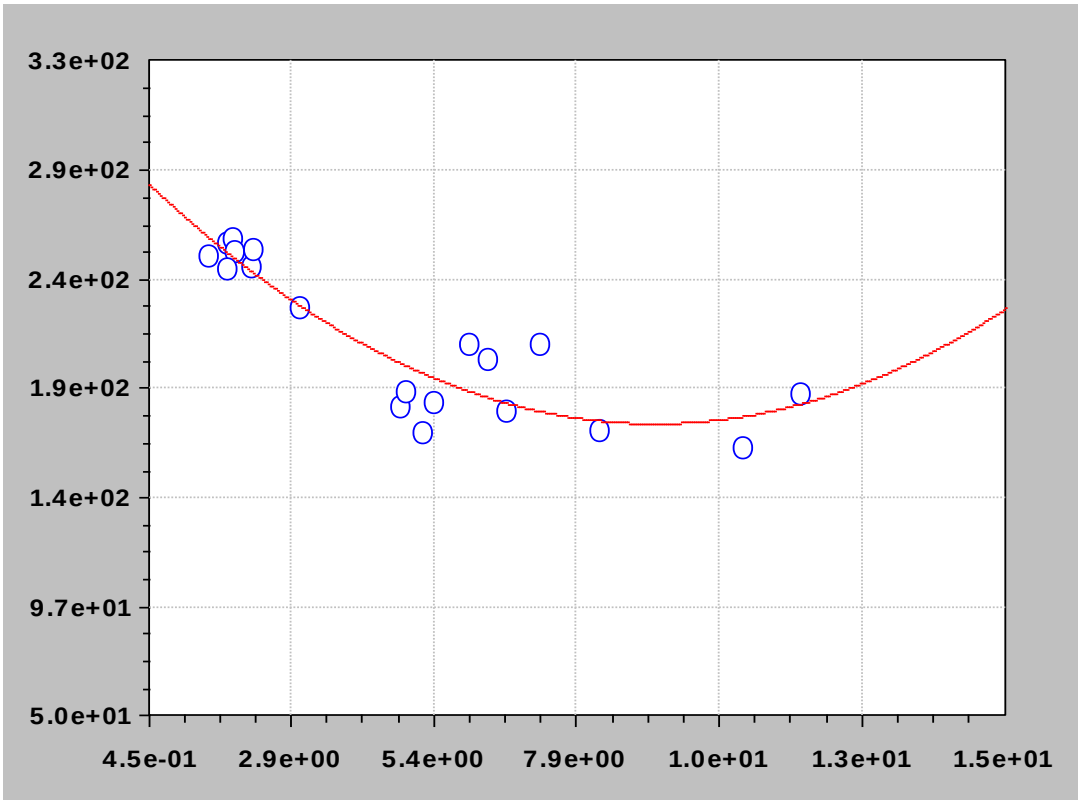

Figure 5.2: Plot of Tc Vs Moisture of the coal samples.

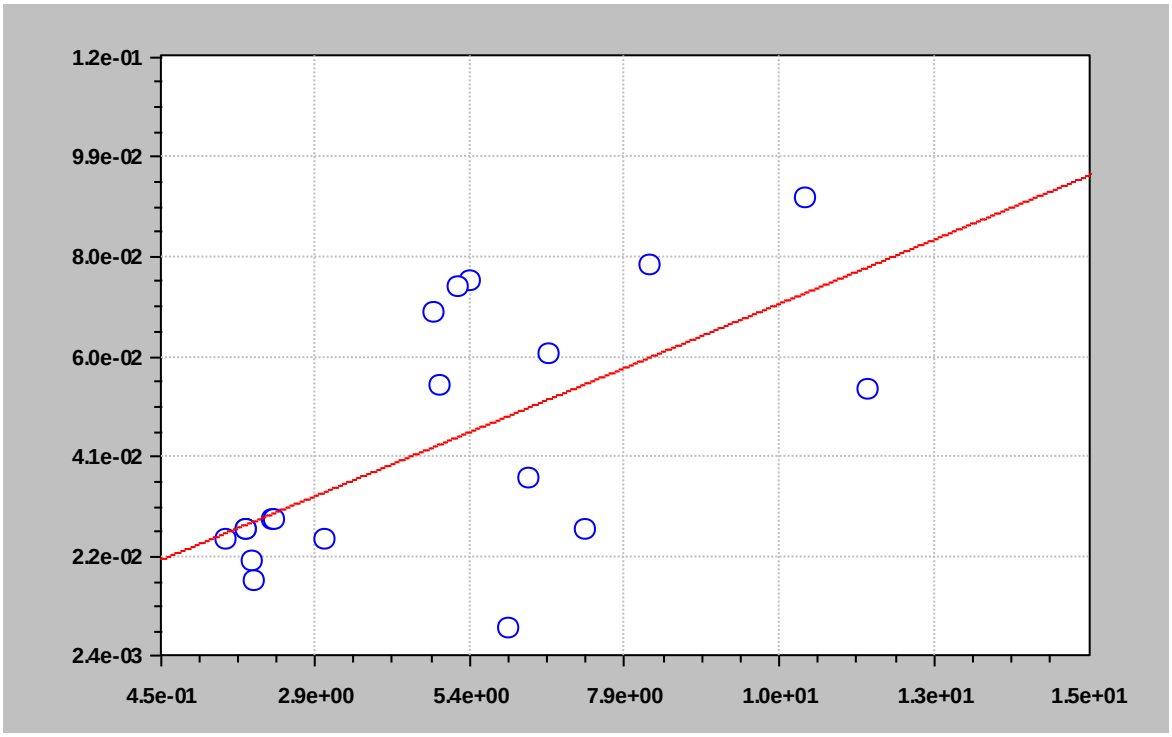

Figure 5.3: Plot of IIA slope Vs Moisture of the coal samples.

5.2 CONCLUSION

From the experimental investigation it was found that the coal samples from SECL were very highly susceptible to spontaneous heating, whereas the samples from BCCL and CCL were found to less susceptible to spontaneous heating. From the correlation study it was found that the moisture content has profound effect in the spontaneous heating of coal. Higher the moisture content of the coal sample, higher is its susceptibility to spontaneous heating.

It is hoped that the outcome of the project work will help the practicing field engineers to plan their workings in advance so that spontaneous heating of coal leading to mine fires can be avoided. Adequate precautions may be adopted in case of high moisture coals, which are more susceptible to spontaneous heating. Other intrinsic parameters such as porosity and surface area etc. may also be determined so that the forecasting of the spontaneous heating of coal can be more authentic.

Chapter - 06

REFERENCES

6. REFERENCES

Banerjee, S.C. Spontaneous Combustion of Coal and Mine Fires, Oxford & IBH Publishing Co, 1985, Pp. (1-40).

Banerjee, S. C. and Chakravarty, R. N. (1967). Use of D.T.A. in the study of spontaneous combustion of coal. Journal of Mines, Metals and Fuels, January, Pp. (1-5).

Beamish B.B. and Arisoy A. (2008): Research project report on "Effect of intrinsic coal properties on self-heating rates", 12th U.S./North American Mine Ventilation Symposium, ISBN 978-0-615-20009-5.

Bhatt, S. and Agarwal, P.K. (1996)."The effect of moisture condensation on the spontaneous combustibility of coal, Fuel", Volume 75, Issue 13, Pp. (1523-1532).

Bhattacharya, K.K. (1971). "The role of absorption of water vapour in the spontaneous heating of coal, Fuel", Volume 50, Issue 4, Pp. (367-380).

Carras J. and Young B. C. (1997) "self-heating of coal and related materials: models, application and test methods", Program Energy combustion science Vol. 20, Pp. (1-15).

De-ming W., Xu-yao Q., Xiao-xing Z. and Jun-jie G. (2009): The 6th International Conference on Mining Science & Technology on "Test method for the propensity of coal to spontaneous combustion", Procardia Earth and Planetary Science 1, Pp. (20–26).

Defaveri D.M., Zonato C., Vidili A., and Ferraiolo G.: Journal of Hazardous Materiakr, 21 (1989) on "theoretical and experimental study on the propagation of heat inside deposits of coal", Institute of Science and Technology of Chemical Engineering University of Genoa, 16145 Genoa (Italy), 1st August, Pp. (135-140).

ENERGY STATISTICS 2012 (Nineteenth Issue), central statistics office ministry of statistics and programme implementation government of India New Delhi.

Gouws, M.J., Wade, L., The self-heating liability of coal: Predictions based on composite indices, Mining Science and Technology 9 (1), 1989, Pp. (81-85).

I.S. (Indian Standard): 1350 (Part-I) – 1984, Methods of Test for Coal and Coke: Proximate Analysis, Bureau of Indian Standards, New Delhi, Pp. (3-28).

I.S. (Indian Standard): 1350 (Part II) - 2000, Methods of Test for Coal and Coke: Determination of Calorific Value, Bureau of Indian Standards, New Delhi, Pp. (3-24).

Jain A, Assessment of spontaneous heating susceptibility of coal using differential thermal analysis, B.Tech. Thesis, 2009, Pp. (1 – 25).

Jones J. C. and Vais M. (1991): Journal of Hazardous Materials, 26 on "Factors influencing the spontaneous heating of low-rank coals", School of Chemical Engineering and Industrial Chemistry, University of New South Wales, Kensington, Australia, 17th May, Pp. (203-212).

Kaymakci, E., Didari, V. (2002). Relations between coal properties and spontaneous combustion parameters, Turkish Journal of Engineering & Environmental Sciences, 26, Pp. (59- 64).

Lang L. and Fu-bao Z. International Journal of Coal Geology 82 (2010) on "A comprehensive hazard evaluation system for spontaneous combustion of coal in underground mining", 28th January, Pp. (27–36)

Marinov V. N. (1976): Research on "Self-ignition and mechanisms of interaction of coal with oxygen at low temperatures. Changes in weight and thermal effects on gradual heating of coal in air in the range 20-300°C", Energy operation, Department of Scientific Research, Sofia, Bulgaria, 23rd July.

Mohalik N., Panigrahi D., Singh V., Singh R., (2009), "Assessment of Spontaneous Heating of Coal by Differential Scanning Calorimetric Technique - An Overview", Coal Operators' Conference, University of Wollongong.

Ogunsola O. L. and Mikula R. J. (1990): Research on "A study of spontaneous combustion characteristics of Nigerian coals", CANMET, Energy, Mines and Resources Canada, Coal Research Laboratory. Canada, 25th September.

Panigrahi D. C. and Sahu H. B. (2003): "Classification of coal seams with respect to their spontaneous heating susceptibility—a neural network approach", Geotechnical and Geological Engineering 22, Pp. (457–476).

Panigrahi, D. C., Saxena, V. K. (2001). "An investigation into spontaneous combustion characteristics of coals using differential thermal analysis", Proceedings of 7th International Mine Ventilation Congress, Krakow, Poland. Pp. (495-500).

Ramlu M. A. 2007, "mine disasters and mine rescue", 2nd edition, chapter-1, "mine fires" Pp-2 to 15.

Riley J. T., Reasoner J. W., Fatemi S. M., and Yates G. S. (1987): Journal Article on "self-heating of coal in barges", Department of Chemistry and Canter for Coal Science, Western Kentucky University, Bowling Green, Kentucky, Apr 01.

Ren, T. X., Edwards, J. S. (1997). "Research into the problem of spontaneous combustion of coal". Proceedings of 6th International Mine Ventilation Congress. Pittsburgh. USA. Pp. (317-322).

Sahu H. B., Panigrahi D. C. and Mishra N. M. (2004): "Assessment of spontaneous heating susceptibility of coal seams by differential scanning calorimetry", published in jurnal of mines, metal and fuels, Pp. (118-121).

Sahu H. B., Panigrahi D. C., Mishra N. M., (2005): "Assessment of spontaneous heating susceptibility of coal seams by experimental techniques - a comparative study", International Symposium on Advances in Mining Technology and Management, IIT, Kharagpur, November 29-Dec 2, 2005, pp. (459-465).

Sahu H. B., Panigrahi D. C. and Mohapatra S. S. (2009): Presented at Ninth International Mine Ventilation Congress, New Delhi, India, "classification of coal seams with respect to their spontaneous heating susceptibility using k-means is clustering", November 10-13, Pp. (273-287).

Singh, R. N., Demirbilek, S. 1987. Statistical appraisal of intrinsic factors affecting spontaneous combustion of coal, Mining Science and Technology, 4, Pp. (155-165).

Tarafadar M. N. and Guha D. (1989), "Application of wet oxidation processes for the assessment of the spontaneous heating of coal, Fuel". Vol. 68, Pp. (315 – 317).

Xie J., Xue S., Cheng W. and Wang G.: International Journal of Coal Geology-85 (2011) on "early detection of spontaneous combustion of coal in underground coal mines with development of an ethylene enriching system", 14th October, Pp. (123–127).

Yuan W. and Smith A. C. (2010): Research on "Effects of ventilation and gob characteristics on spontaneous heating in long-wall gob areas", NIOSH Pittsburgh Research Laboratory, Pittsburgh, Pennsylvania, USA.

http://www.censin.com/calorific-value-of-coal/